

**THE MARVELS
AND MYSTERIES
OF SCIENCE**

*Dome containing
movable flat mirrors*

The tube

150 feet

*Outer tower
supporting
dome and tube*

*Hollow posts
containing
supports of
inner tower*

*Pit, 80 feet
deep, below
tower*

*Solar image
formed in the
observing room*

This tower at Mount Wilson Observatory, California, is used in the study of the sun

THE MARVELS AND MYSTERIES OF SCIENCE

An outline of scientific knowledge in astronomy,
biology, chemistry, physics, geology, anthropology
written in popular style by

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INTRODUCTION

SCIENCE had its beginnings, without doubt, before the dawn of history. A vast amount of evidence has been found in the ruins of ancient civilizations—no matter how primitive—indicating early developments of architecture and other crafts which have been the foundation of science. Every tool to be efficient had to be based upon correct principles of what we call science, even though these principles were imperfectly understood at the time.

Man became a scientist when he began to use tools, perhaps even before. The first tools were probably of wood and stone, with little or no fashioning; with little understanding of the principles of mechanics. The early users of clubs, hammers, and stone knives, however, must have had some rudimentary notions of the principles of simple mechanics, such as levers or inclined planes, or modifications of these, which they learned by the trial and error method. Besides these practical devices, which had to do with self-defense, the gathering of food, etc., many other inventions were made that were the outgrowth of man's innate love of beauty and ornamentation, and of his religion. All the primitive artifacts, the investigation of which has been classified in that all-inclusive branch of science, archaeology, point to the beginnings of science in the dim and distant past.

An isolated fact is not science. Science begins when one fact is compared with another; that is, when a fact is considered in relation to other facts. Science is knowledge correctly classified with respect to interrelated facts. The building blocks of science are the phenomena of nature, and a phenomenon is anything observed to occur. Science depends upon straight seeing and straight thinking. Logic is not a science, although it is an indispensable preparation for the scientific approach. Mathematics is hardly a science, but rather an indispensable tool in the pursuit of scientific truth.

ASTRONOMY

In a survey of the beginnings of science one turns first to astronomy, one of the oldest if not the oldest, of the physical sciences. It seems altogether probable that the first man was the first astronomer, for no doubt he began immediately to make simple astronomical observations, such as that of the rising and setting of the sun. Very soon he began to draw inferences from facts, and to compare one thing with another. This, of course, was rudimentary reasoning—the beginning of science.

It also seems certain that the earliest astronomers were astrologers, believing that the heavenly bodies exercised a definite influence upon the lives of men. This belief, which was in the beginning well-nigh universal, has prevailed until the present day. With the progress of astronomy, a great rift has developed between astrology and astronomy, until at the present time

there is probably not a single astronomer in the world who believes that the planets exercise any influence over the lives of men.

According to the earliest notions of which we have record, the earth was believed to be flat, and limited in extent to the restricted geographical knowledge of the time. Surprising as it may seem, parenthetically speaking, there is a small group of adults in this country which still believes that the earth is flat. The earliest cosmologies which included this belief were indeed childish.

The early Egyptians conceived of the universe as four-sided, with Egypt in the center. Egypt occupied a level plain surrounded by high mountains, with an enormously high mountain peak at each of the four corners. These four high peaks supported the dome of the heavens. According to this conception, the sky was a ceiling over the universe, containing holes through which at night certain gods let down the lamps of the sky—the stars—on cables for the purpose of furnishing beauty and illumination for the human beings. In the morning these same gods pulled up the lamps, as the great god Ra, the Sun, started on his daily journey around the ramparts of the world, riding in his Nile chariot on the celestial river which flowed along the flanks of the mountain range which surrounded the Egyptian plain. In this celestial river the Nile was believed to have its source.

Among the primitive peoples of the world there was a great variety of ideas of the universe, such as the Egyptian, the Babylonian, the Aztec, the Peruvian—all equally fantastic and unscientific. The body of astronomical knowledge that can be properly called scientific dates back at most only a few thousand years, but it is not possible to say exactly when it began.

Although we must go back to the ancient Chinese astronomers for our earliest records of eclipses, sunspots, and probably comets, it seems that these oriental peoples were not adept at framing working hypotheses based upon the facts that they observed. Instead we must turn to the peoples of the Mediterranean region for the rudimentary approximations of truth about the universe.

In prehistoric times the Chaldeans discovered the interval of the recurrence of eclipses, which they named the *saros*, signifying repetition. They observed that eclipses must repeat themselves after an interval that is the least common multiple of the period of the revolution of the moon around the earth with respect to the sun and the intervals of the arrival of the sun at the same one of the moon's nodes (eclipse year).

As early as 280 B.C. Aristarchus of Samos set forth the notion that the earth travels around the sun. But his successors, Hipparchus, Ptolemy, and others rejected this view in favor of a stationary earth. This latter theory held sway for more than a dozen centuries.

The Greek astronomer, Hipparchus, who has been called the father of astronomy, in 125 B.C. discovered the precession of the equinoxes by comparing the length of the year, determined by dates when certain bright stars could first be seen in the dawn after the sun had passed them in its annual motion, with the length of the year of the seasons determined with the gnomon. This amazing discovery of a motion of the earth that requires nearly 26,000 years for the completion of one circuit, sometimes called the Great Year, could

not be explained at the time, but had to wait 1800 years for the mind of Newton to explain the physical cause.

The old earth-centered theory of astronomy was highly developed during the second century A.D. by Ptolemy, the great Alexandrian astronomer, and has since been known as the Ptolemaic System. According to this theory the earth was believed to be the stationary center of the universe, and it was thought that the sun, moon, stars, and planets revolved around the earth. These were, of course, natural and logical conclusions. Everyone saw the sun rise in the east, pass across the sky, and set in the west, and the following morning they saw it again rise in the east. It certainly seemed that the sun went round the earth. They also saw the moon rise in the east, pass across the sky, and set in the west, and the next day they saw it rise again in the east. It seemed that the moon surely went round the earth. (To be sure the moon does go round the earth, but it takes about a month to make the trip. Consequently this revolution cannot account for its daily rising and setting.) The ancients observed the stars and the planets rise and set every day, and concluded that they also revolved around the earth as a center.

These early astronomers did not understand the nature of the planets, but they had observed and named all that are visible to the naked eye. They had observed, too, that the planets did not keep their relative positions among the stars, but that they wandered about in the sky. In fact, the name *planet* in its original Greek means *wanderer*. The astronomers had noticed that, while Mars, for example, traveled from west to east most of the time, occasionally it stopped its eastward motion and moved westward for a few weeks. To explain this retrograde motion, they believed that Mars traveled around a small circle, the center of which moved around the earth in a much larger circle. This small circle was appropriately called an epicycle. The other planets were also believed to travel in epicycles. This notion provided an explanation that satisfied the astronomers for a dozen centuries—a very long life for any theory. As Sir James Jeans says, "Science advances rather by providing a succession of approximations to the truth, each more accurate than the last, but each capable of endless degrees of higher accuracy."

Although Aristarchus, nearly three centuries B.C., suggested that the earth revolves around the sun, he did not get far with the theory. The serious consideration of this notion, together with the correlated one of the rotation of the earth on its axis to explain the daily rising and setting of the heavenly bodies, began upon the publication in the middle of the 16th century of *De Revolutionibus Orbium Coelestium* (Concerning the Revolutions of the Heavenly Bodies) by Copernicus.

Although this epoch-making book was published in 1543, it was fully a hundred years before the new sun-centered theory was generally accepted. It was nearly ninety years later (1632) that Galileo published his famous *Dialogues*, which contain a brilliant defense of the Copernican system, for which he was tried for heresy and forced to renounce his teachings. In our oldest colleges in America, Harvard and Yale, the old Ptolemaic theory and the new Copernican theory were taught side by side, as though one were as important as the other. Perhaps Galileo deserves more credit than any one

else for the establishment of the new sun-centered theory which has finally come to be accepted by all the astronomers in the world. In fact, it is no longer a theory, for it has been proved beyond the possibility of a doubt.

PHYSICS AND CHEMISTRY

In the sphere of physics and chemistry we have seen a similar growth and evolution of ideas. As astronomy grew out of astrology, chemistry grew out of alchemy. In the latter case, however, we have a surprising history. The alchemists of ancient times sought vainly by repeated experiment to transmute the baser metals into gold. As the science of chemistry developed, scientists concluded definitely that it was impossible to transmute one metal into another. But now, with the knowledge of the twentieth century, it has been found possible to do this very thing. Starting with the primitive notion that earth and water and air and fire were "elements," it was gradually determined that the fundamental elements were iron, carbon, oxygen, etc., to the number of 92. For a time, and for what seemed to be good reasons, this was believed to be the complete number. Then came the isotopes; it was discovered that there was more than one kind of hydrogen, more than one kind of iron, more than one kind of uranium—and the end is not yet.

With the smashing of the atom, our chemistry and physics have been profoundly changed. These subjects are now in such a state of flux that it seems impossible to unify the whole, as the human mind seeks to do with any body of knowledge.

Some 250 years B.C., the brilliant mathematician, Archimedes, who was the son of an astronomer, developed the principle of the lever and invented his screw-pump—achievements in practical physics or mechanics.

One of the most famous achievements of Archimedes is the principle which states that, if a solid be weighed in a fluid, it will be lighter than its true weight by the weight of the fluid displaced. And every boy or girl, who has studied high school physics, is familiar with the application of this principle in the story of the crown made for Heiro, King of Syracuse. As the story goes, Heiro suspected that the metal of his crown was not pure gold but that it was mixed with silver, and he engaged Archimedes to determine the proportion of gold and silver in the crown. Archimedes observed that when he got into a level-full bath tub the volume of the water which overflowed was equal to that of his body, and he reasoned that his body was buoyed up by an amount equal to the weight of the water displaced. This observation gave him the solution of the problem, and he is said to have run home from the baths naked, shouting "Eureka! Eureka!" ("I have found it! I have found it!")

The invention of the hydrostatic scales near the close of the sixteenth century by Galileo—no doubt independently—seems to be based upon the same principles.

Archimedes invented a great number of mechanical contrivances, but considered these unworthy of a philosopher. To him his achievement in pure mathematics was more important, as no doubt it was.

Experimental science really begins with Galileo, who discovered the laws of falling bodies, and the laws of the pendulum. He was the creator of the science of dynamics; he constructed the first thermometer; and he was the first to use the telescope for astronomical observations.

Among his astronomical discoveries were the four large moons of Jupiter, the mountains and craters on the moon, the Milky Way as a great cloud of stars, sunspots, and the fact that Venus goes through the gibbous as well as the crescent phases. (This observation proved to be the most crucial blow ever received up to that time by the Ptolemaic theory. It simply could not be explained by the earth-centered theory of astronomy.) Not only was Galileo the first to see Venus as a waxing and waning crescent, and in the gibbous phases, but he was also the first to see the rings of Saturn, although with his primitive telescope, which magnified only thirty diameters, and was not corrected for chromatic or spherical aberration, he never quite made out the true character of these rings.

Modern physics begins with Galileo, and the next titan in this field was born in the same year in which Galileo died. This was Newton, born on Christmas day, 1642, and like Galileo, a mathematician, physicist, and astronomer. Among his many achievements are three of the greatest discoveries in the history of scientific thought—the Differential Calculus, the Composition of Light, and the Law of Gravitation.

On the day that Newton first passed white light through a triangular prism of glass and separated it into all the colors of the rainbow, he laid the foundation of the spectroscope, which has contributed more to the science of astronomy than any other instrument.

When Newton conceived the explanation that light consists of corpuscles of matter shot out from the light-giving bodies, he gave us a theory that prevailed until the nineteenth century, when the physicists concluded that it could not explain certain phenomena, and substituted the undulatory, or wave, theory. As often happens with old and dignified theories, the wave theory was given a jolt in 1905 by Einstein in his development of the photo-electric equation, which, as Millikan has pointed out, necessitated our return to at least a semi-corpuscular theory of the nature of radiant energy. Professor Arthur H. Compton recently stated, "Perhaps the best picture that one can give of the relation between waves and particles is the analogy of sheets of rain which one sometimes sees in a thunderstorm. We may liken the waves to the sheets of rain that one sees sweeping down the street or across the fields. The radiation particles would correspond to the rain drops of which the sheet is composed."

Newton still looms as probably the greatest mind of all time, but a number of his conclusions have had to be modified during the early years of the twentieth century. With his special theory of Relativity (1905), Einstein set forth the equation expressing the interconvertibility of mass and energy. Before that time physicists accepted as laws the conservation of matter and the conservation of energy. In other words, it was believed that matter could not be destroyed, that if it disappeared in one form it was simply changed to another form. It was believed that energy could not be destroyed,

that if it disappeared in one form it reappeared in another form of energy. It is not now believed that matter or energy can really be destroyed. The new idea is that they are interconvertible. For example, more than 4,000,000 tons of the sun's mass are converted into radiant energy every second.

Newton considered space and time and mass and force as *absolute*. Einstein has shown that space, time, and mass are *relative*. Newton looked upon gravitation as a force, but according to the theory of Relativity the notion of force must be given up since it does not represent anything that is genuinely to be found in the physical world. Although "force" is no longer to be regarded as one of the fundamental concepts of physics, but only as a convenient way of speaking, as Bertrand Russell points out, it can still be employed, like "sunrise" and "sunset," provided we realize what we mean. Often it would require very roundabout expressions to avoid the term "force."

After correcting Newton, as has been remarked, it remained to correct Euclid, and it was in terms of non-Euclidean geometry that Einstein stated his theory of relativity, according to which it is believed that no complete description of an occurrence in nature can be made with the three co-ordinates of Euclidean geometry—length, breadth, and thickness—but that a four-dimensional space-time system must be conceived. Minkowski stated the essence of this conception in the following prophetic words: "Henceforth, space by itself and time by itself shall sink to mere shadows, and only a union of the two shall preserve reality."

A generation or two ago, physics and chemistry seemed quite distinct, when the structure of the molecule was left to the chemists, but in reality there are no hard and fast lines in nature, and the new physics has gone into the structure of the atom. In derivation, the word "atom" means "cannot be cut or divided," but the modern splitting and smashing of the atom makes this name a misnomer.

Chemical principles have been in use since time immemorial in the preparation of metals, the making of glass, the tanning of skins, the use of dyes, the preparation of drugs, but the science of chemistry can hardly be looked upon as more than 2000 years old. The first chemists were certainly nearly all alchemists, who sought in very unscientific ways to transmute the baser metals into gold. Aside from the practical arts mentioned above, chemistry was identical with alchemy for some sixteen hundred years.

From the beginning of the Christian era until the seventeenth century, the prevailing view was that matter was homogeneous and divisible without limit. Each of the original "elements," earth, air, fire, and water, was believed to represent in a rather indefinite, though natural way, certain qualities. Later mercury, sulphur, and salt were added, making seven "elements."

As late as the first half of the seventeenth century, van Helmont, who did great service in establishing scientific chemistry, wrote a careful description of a transmutation of mercury into gold, which he claimed he performed himself with a portion of the Philosopher's Stone that had been given him.

In the latter half of the seventeenth century, Robert Boyle did great service in setting forth that the alchemical method of treating chemistry as a secret and mystical art was wrong, and that this branch of the physical sciences

should be supported by experiment. It is to Boyle that we owe the notion that any substance must be regarded as a fundamental element until it can be further resolved into simpler substances.

In an effort to understand fire and the nature of combustion, the theoretical chemists evolved the conception of *phlogiston* which was considered by some of the greatest chemists of the eighteenth century as an element, a real, fundamental substance.

Priestley discovered a number of important chemical compounds as well as the element, oxygen. Scheele discovered oxygen independently, and also the element chlorine and a number of compounds. Cavendish made important studies of carbon dioxide and hydrogen. These three famous chemists held the phlogiston theory to be true, in spite of the vast amount of pioneer research they had done. Finally it was upset by Lavoisier. This French chemist proposed a system of chemistry based simply on the combination and decomposition of real substances that could be isolated and examined in the laboratory. He ruled out all hypothetical "principles."

In the first two or three years of the nineteenth century, Dalton developed the atomic theory of matter, out of which grew the chemical formulae of modern chemistry. About a century later Arrhenius gave us the electrolytic or dissociation theory which proved to be an epoch-making step forward.

Then came the discovery of radioactivity, and the development of physical chemistry, another tremendous advance, which led to the understanding of the structure of the atom and the transmutation of elements.

Since 1850 we have seen almost the entire unfolding of organic chemistry. The chief source of organic compounds is coal tar, from which have been developed thousands of important chemicals including tens of thousands of shades of aniline dyes, synthetic perfumes, oil fuels, sugars, and drugs.

MEDICINE AND SURGERY

In a similar way we have seen the development of the scientific approach in the applied science of medicine, from the superstitious stage with its demoniacal "possessions" and supernatural influences of a few hundred years ago, to the present definite diagnosis and intelligent treatment. With the new electronic microscope, we can now photograph the filterable viruses. Although many diseases have been brought under partial or entire control, such as malaria, diphtheria, pneumonia, and diabetes, and some practically eradicated from the face of the earth, there are still many unsolved problems, for example, cancer and arthritis. Surgery has made vast progress from the days of blood-letting for practically every ailment to the modern intricate operations, with anaesthetics, upon the brain, heart, and other vital organs.

The development of medicine and surgery has been made possible with the growth of our knowledge of anatomy, physiology, and general biology, together with the evolution of physics and chemistry. One of the newest lines of research is the tracing of fundamental elements in food, which have been made radioactive with the new cyclotron, through the various body organs.

PLANTS AND ANIMALS

Scientists do not know at all definitely when life began on the earth, although it certainly must have appeared many, many millions of years ago. The earliest idea of the origin of plants and animals is generally known as the special creation theory, according to which it was believed that all kinds of living things, as well as the extinct forms found only as fossils, were created just as they are. Of course, according to this conception, it was not believed that the fossil plants and animals ever had lived. Although certain primitive peoples had strange, unscientific notions of abrupt changes in living creatures, the belief in special creation grew with the development of civilization. And creation usually meant making something out of nothing by a Supreme Being. This belief was almost universal until 1859, when Darwin published his book, *The Origin of Species*. At first Darwin's idea of the relationship of plants and animals and the descent (or origin) of complex forms from simpler forms was strongly opposed because it was thought to be contrary to the holy scriptures in Christian countries—reminiscent of Galileo's teaching of astronomy. But by the beginning of the twentieth century, practically all botany and all zoology were taught from the standpoint of evolution. It should be stated, however, that there are still a great many laymen in America who feel that man should not be included in this evolutionary history. Remembering that it was more than one hundred years after the publication of Copernicus's book in 1543 until the sun-centered theory of the solar system was generally accepted, there is no great reason for discouragement, as only about four score years have passed since Darwin set forth the idea of evolutionary development.

We may not know with certainty the location of the "cradle of civilization," but some students of anthropology and ethnology accept the theory that man first appeared in Asia. However that may be, it seems certain that the American Indians—all the aboriginal inhabitants of both North and South America, including the Eskimos—came from Mongoloid ancestors, who probably crossed the Bering Straits to this continent from Asia. The Eskimos were probably a more recent immigration than the Aztecs, the Mayas, the Incas, and the many other tribes of so-called Indians. Here they developed civilizations of various degrees of complexity. According to Dr. Herbert J. Spinden, a high authority on the Mayan civilization, the Mayas, when they had reached the peak of their development, were the best astronomers in the world at the time, not excepting the peoples of the Mediterranean region. Dr. Spinden also states that the Mayas "invented signs for zero and discovered the principle of 'local value' in the writing down of numbers centuries before these ideas (which are fundamental to higher mathematics) were known in the Old World."

As with the physical world, so with the biological world including man, there is nothing unchangeable except eternal changeableness.

"Nothing that is human is alien to me."

CLYDE FISHER

THE WONDERS OF THE HEAVENS

CHAPTER 1—THE SUN

TO those of us who live in the United States of America, our nearest city seems a very large place and New York City or Chicago seems enormous. If we complete an automobile tour of our country we feel we have covered a tremendous area and that we should not care to do the same with the whole continent of North America as the objective. Yet North America is but one of five continents, and these combined occupy hardly one-fourth of the area of the whole earth.

Our imagination reels at the thought of the earth's size and is really incapable of grasping the significance thereof. How then can we expect to be able to imagine the size and significance of some of the other planets that together with the earth circle around the sun? And how much more difficult is it for us to try to imagine the dimensions of the sun, and to gain some idea of the composition of this great globe that maintains its heat and light throughout the ages and remains undimmed in its majestic brilliance.

The earth's diameter is about 7,920 miles, but that of the sun is over a hundred times as great. In fact, if placed side by side, 109 planets of the same size as the earth would be required to extend from one side of the sun to the other.

If a firm of contractors undertook to build up a body as large as the sun, and if their transport arrange-

ments enabled them to convey to the site every hour a quantity of material equal to the volume of the earth, their contract would not be completed for 150 years, working three 8-hour shifts to the day. Mathematicians are able to tell us that the sun's mass is 332,000 times that of the earth and that its density is about one-fourth that of the earth.

To express the sun's mass in tons we should have to write down the figure 2 and follow it with 27 ciphers to show the number as two million million quadrillion! Few people can visualize a thousand, and even fewer can imagine a million, so that no one can hope really to comprehend what is represented by such an astronomical figure as two million million quadrillion.

It is known that, compared with the relatively solid earth, the sun is gaseous in nature. Remembering that every particle of matter attracts every other particle—as we shall explain in greater detail later—we are able to understand more clearly how it is that the sun has such a powerful gravitational effect on the earth and on the other planets that circle round it.

INTENSITY OF SUNLIGHT

The light given out by the sun is intensely bright—four times as bright as the brightest part of the electric arc.

The sun's heat is enormous and several interesting calculations have been

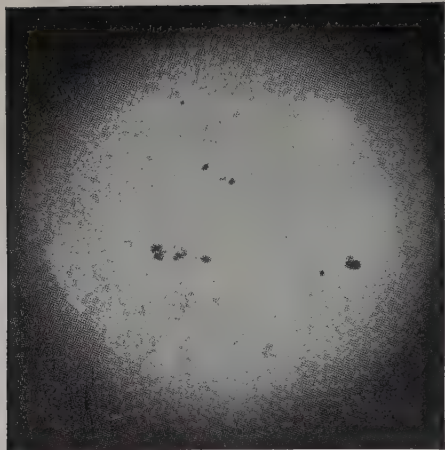


Fig. 1. The sun, showing three groups of sunspots and characteristic fading at the edge of the disc

made in an attempt to illustrate it. For example, it has been determined that if the whole of the solar radiation could be concentrated on a solid column of ice nearly three miles in diameter stretching from earth to sun—about 93,000,000 miles—it would melt it in one second, and the resulting water would be turned to steam in a period of time not more than eight seconds!

An estimate of the surface temperature of the sun places it at $10,000^{\circ}$ F. and its radiation at nearly 900,000,000 calories per square meter per minute, or nearly 20,000 calories per square meter per minute at the earth's distance. To obtain this amount of heat by combustion would require the burning every hour of a layer of anthracite coal 16 ft. thick and extending over the entire surface of the sun. Lord Kelvin, British physicist of the late nineteenth century, calculated that if the sun were composed of solid coal and produced its heat by combustion, it would burn out in less than 6,000 years.

We must remember, too, that the earth receives only a very minute quantity—about $\frac{1}{2,000,000,000}$ part—

of the total heat and light that is radiated by the sun. We can well illustrate this by supposing that the sun's radiation is converted into money. If we take the sun's annual expenditure as being \$2,000,000,000, the earth would receive an annuity of about \$1 only. Yet if as little as 10 per cent of this small quantity were cut off, large areas of the earth would become frozen wastes. The remainder of the sun's radiation passes into space and apparently is wasted, except where it falls on the other planets of the solar system.

Endless discussions have taken place as to how the sun maintains its enormous output of light and heat, which does not seem to have appreciably diminished throughout the centuries. So far as the earth's surface is concerned it would be difficult to attribute any changes in vegetable and

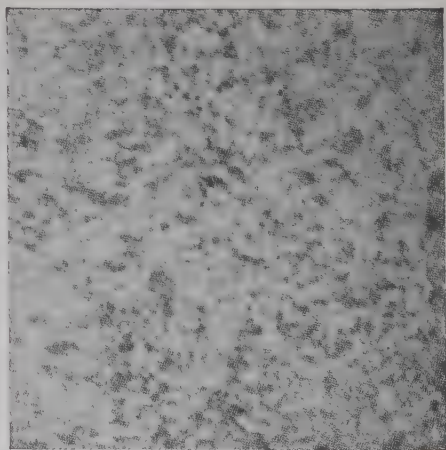


Fig. 2. The sun's surface, showing blurring due to rise of heated gases from the central mass

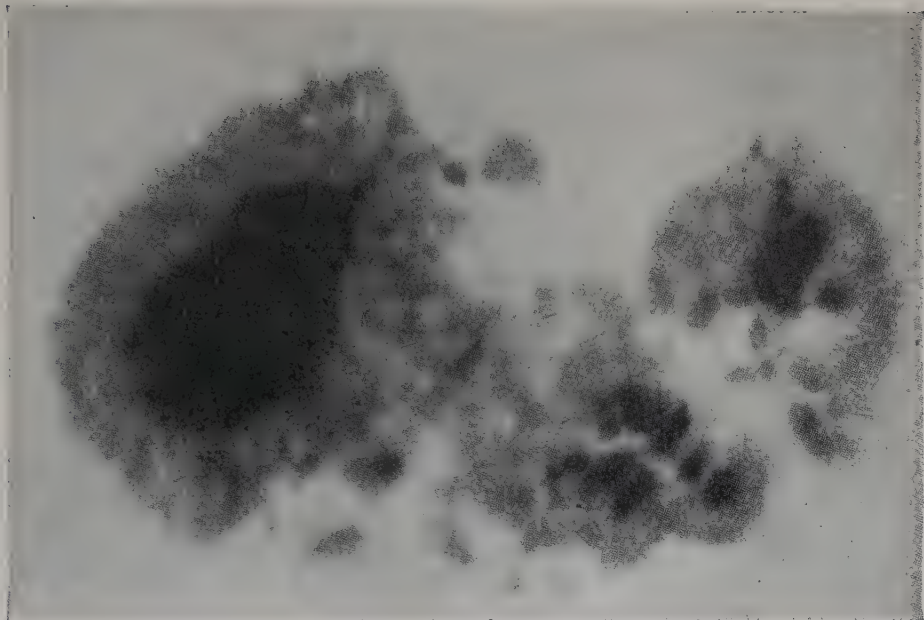


Fig. 3. Large sunspot group photographed at Greenwich Observatory. The dusky penumbra together with several smaller spots can be clearly seen in this picture

animal life to a diminution in the amount of heat received from the sun, for local conditions play a more important part in this respect. Otherwise, we might be led to suppose that the amount of heat received is increasing rather than diminishing, since we know that at times in the earth's history the temperate zones were covered in part by a sheet of ice many hundreds of feet thick. But although this huge ice mass has since melted away, it is probably not because of any increase in the heat coming from the sun.

HELMHOLTZ'S THEORY

The eminent German physicist Helmholtz (1821-94) advanced a theory of radiation that was after a time almost universally accepted. He suggested that the sun's heat is the

result of the energy of the sun's gradual contraction. He found that a contraction of the sun to the extent of 250 ft. per annum—slightly over a mile in 21 years—would be sufficient to account for the annual output of heat. On this assumption the deduction is that in 100,000 years the mean temperature of the earth will be 5° lower than it is now. Other calculations suggest that even if contraction were taking place at the rate mentioned, the sun's mass is so enormous that its temperature will remain more or less as it is for at least 20,000,000 years—only a moderately long period when calculated in terms of astronomical time.

The contraction theory of Helmholtz, at the time it was proposed (1854), seemed to provide a sun with a past history of sufficient duration.

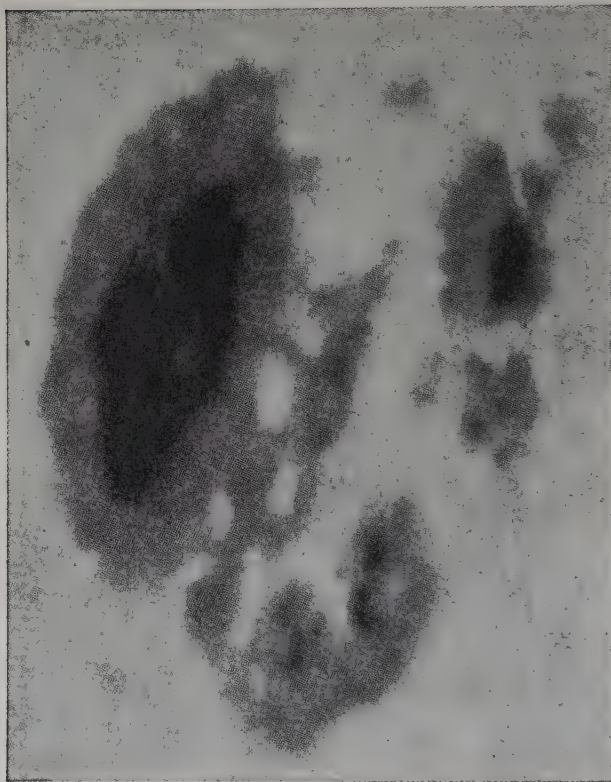


Fig. 4. The same spot as in Fig. 3, three days later. It has been split by a bridge and some of the smaller spots have disappeared

And even until the close of the nineteenth century it was generally conceded to afford an adequate explanation of the vast production of energy (heat and light) by the sun. But present-day geological evidence indicates a much older sun than allowed by the Helmholtz theory. Consequently it is now assumed that the contraction of the sun plays only a minor role in keeping up its heat.

The energy of the sun and of the other stars is now believed to be produced by changes in the atoms within these vast gaseous bodies. The latest theory was presented by Hans A.

Bethe, Professor of Physics in Cornell University. While this solution of the problem appears to have been accepted by the world's leading astrophysicists, it is too technical and abstruse to be treated here.

THE SURFACE OF THE SUN

A photograph of the sun (Fig. 1) shows it to be a globe with clean-cut edges that are less bright than the central part. Towards the extremity of the disc this darkening may amount to a loss of as much as 60 per cent of the light at the center. This shows that its surface is gaseous, for were the sun solid or liquid its surface would appear to be equally bright at the edge and at the center.

The darkening of the edge, or "limb" as it is called, is caused by absorption of light by the gaseous envelope that surrounds the sun, which corresponds to the atmospheric envelope that surrounds the earth.

The surface of the sun presents a mottled appearance as though covered thickly with tiny elongated grains (Fig. 2). Over the surface are to be seen irregular streaks that are brighter than the surrounding surface. These are the *faculae* (a Latin word meaning "little torches"). The *faculae* are most numerous in areas away from the poles, where, in fact, they are not

often seen. They are best seen towards the limb where, because the relative brightness of the surrounding surface is somewhat dimmed, as already explained, they are more conspicuous. Actually, the *faculae* are the crests of great clouds of vapor arising from the depths of the sun, and they may measure 40,000 miles in length and 5,000 miles in breadth, or even more.

Very often spots are seen on the surface of the sun, as shown in Fig. 1. These spots vary in size from the tiniest point to huge dark markings that look like blots of ink on a clean plate. The sun always used to be regarded as a symbol of unblemished purity, and when Galileo discovered spots on it through his newly invented telescope, over 300 years ago, he was very perturbed by what he saw. The explanation of them is as follows. The surface of the sun that we see—called

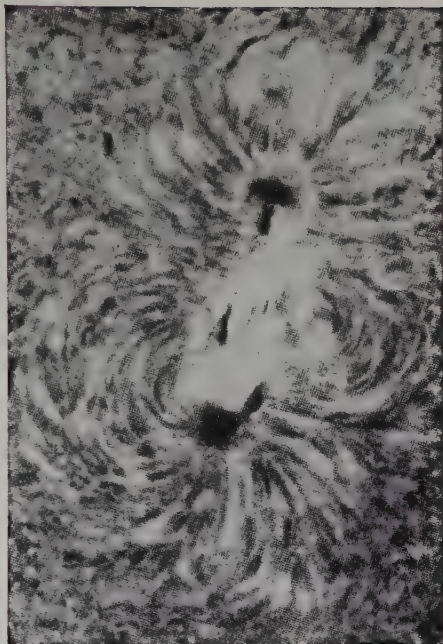


Fig. 5. Cloud of hydrogen bridging two sunspots

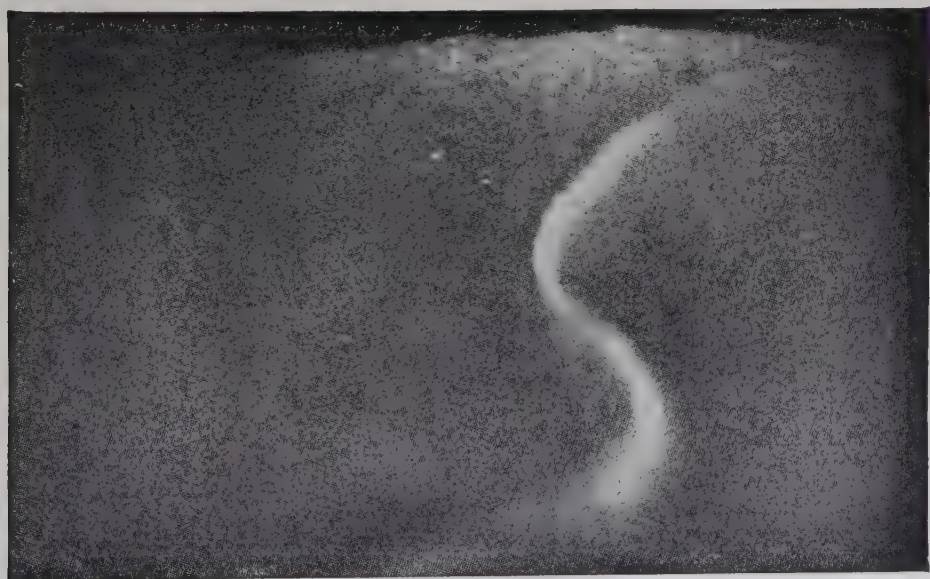


Fig. 6. The Aurora Borealis is a cathodic ray discharge, associated with solar activity. It occurs from about sixty to nearly six hundred miles above the earth and is most frequently seen near the Arctic Circle

the "photosphere"—is a layer of highly heated gases that surrounds the central mass, and sunspots are openings in this gaseous envelope.

Sunspots are like safety valves—they allow highly compressed and heated gases to escape from the sun's interior through the agitated photosphere. Sunspots are whirlpools, or vortices, in the solar atmosphere. When a gas under pressure is suddenly released and allowed to expand, it cools in accordance with a natural law, and this is what happens when a sunspot is formed. What is below the photosphere we can only surmise. When the great solar storms that cause sunspots take place, the photosphere is torn apart and we can see through the "rift in the clouds" that

the depths below appear black (Figs. 3 and 4). From this we might suppose that the interior of the sun is cool, but we must remember that although a sunspot appears black it is only so in comparison with the excessive brilliance of the photosphere, just as an arc light appears black if held against the disc of the sun for comparison.

Although sunspots often assume fantastic shapes, as a rule they are more or less circular in outline—at any rate they are nearly always so when they first appear. They are of all sizes—some measure up to 100,000 miles in diameter—and most of them could swallow up the earth with ease (Fig. 11). One of the largest ever seen—in 1905—was so large that

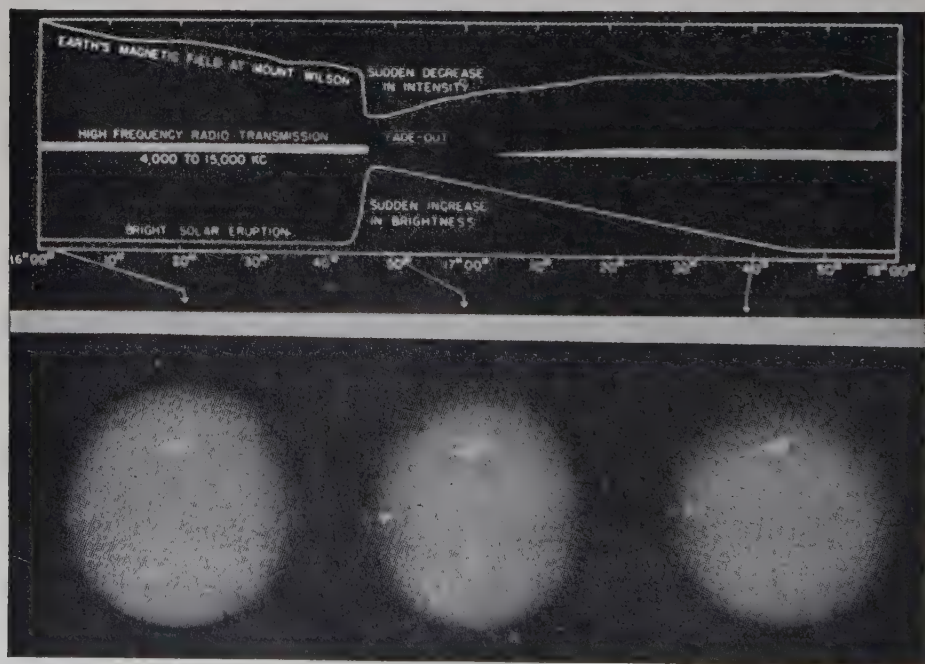


Fig. 7. The relationship between the activity of sunspots and the earth's magnetic field. As the solar eruption (photographed in the lower half) developed, there was a sudden decrease in magnetic intensity and a fade-out of radio signals, as shown by the graph above

STREAMS OF ELECTRONS
ENCOUNTERING THE EARTH
CAUSE MAGNIFICENT
DISPLAYS OF AURORA.

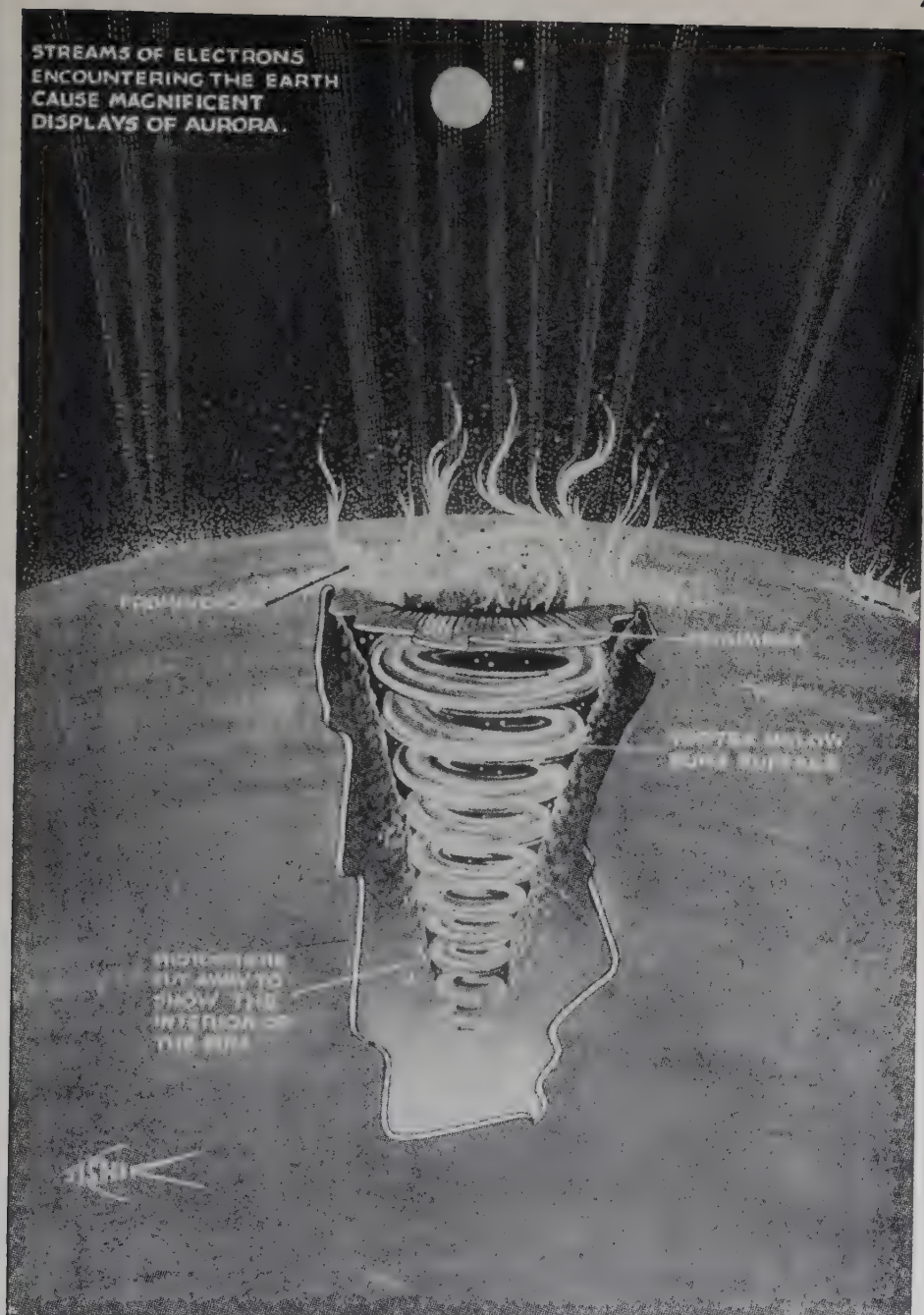


Fig. 8. Structure of sunspot. Sunspots are huge vortices in the envelope of incandescent material round the sun—safety valves allowing gases to escape from inside

THE SUNSPOT CYCLE



Fig. 9. Section of an oak log, showing the concentric annual rings. Each of these rings represents one year's growth

several earths laid side by side could have passed through it without touching its edges. Such sun spots as these can be seen very easily by means of the naked eye when the sun is obscured slightly by mist or cloud, or by looking through smoked glass or through the dark part of a photographic film.

Although there are nearly always some spots on the sun, there are more in some years than in others. They come in waves, fluctuating every eleven and a fraction years and forming a cycle. This sunspot cycle was first discovered in 1843 by Schwabe, a German amateur astronomer, who made all his observations with a small hand telescope. He was awarded the Gold Medal of the Royal Astronomical Society for "the indomitable zeal and untiring energy displayed in bringing his research to a successful issue." The years 1917, 1928, and more recently in 1939, were those of sunspot maximum.

Although they look so very small, and although they are situated so enormously far away, the earth is radically affected by sunspots in more ways than one. It has been definitely proved that the vortices forming the spots are electrical, and in 1922 it was discovered by G. E. Hale, then Director of the Mount Wilson Ob-

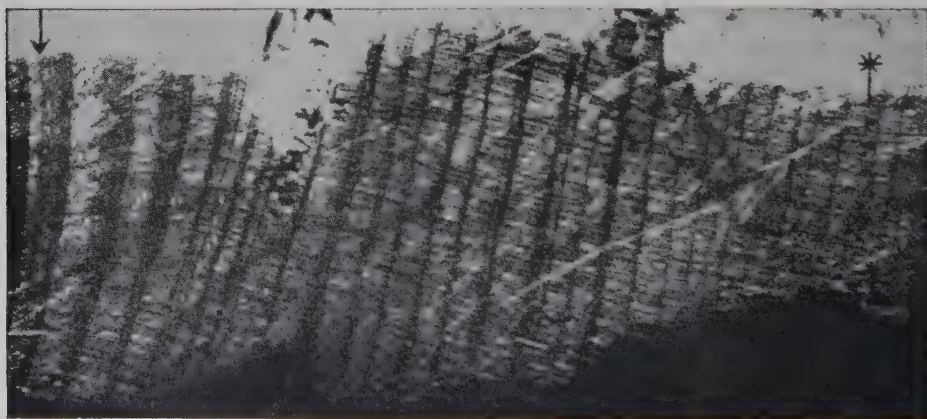


Fig. 10. A log taken from a ruined Indian dwelling. From this scientists have discovered America's medieval weather conditions. The arrow indicates the growth of the tree in 1247, the star, in 1275; the thickness of these rings indicates the rainfall for the year

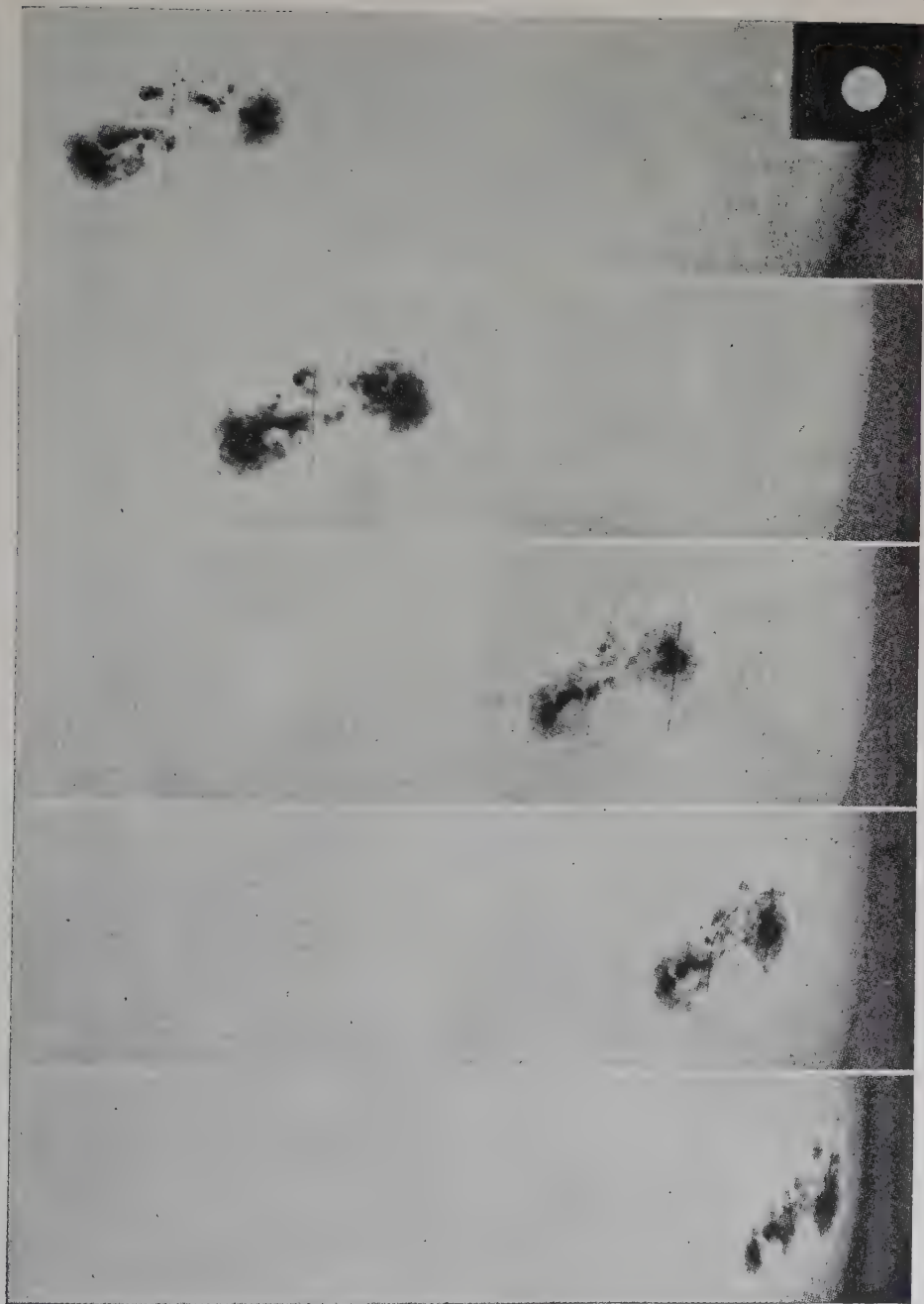


Fig. 11. The day by day movements of a sunspot group observed at Mount Wilson showing how the spots are carried across the face of the sun towards the edge by its rotation. Inset shows size of the earth in comparison with these huge sunspots

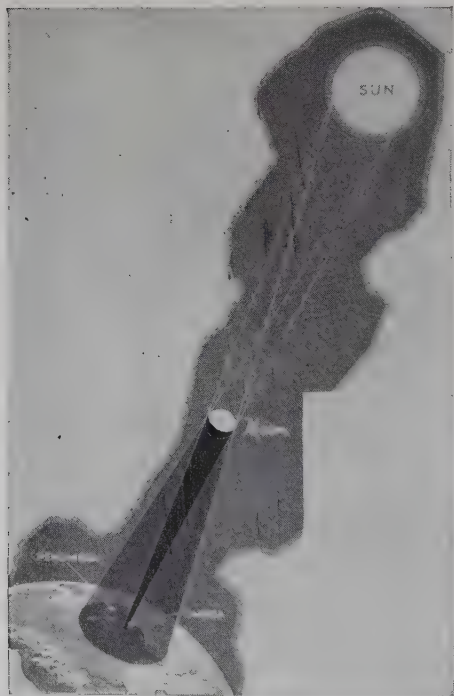
servatory, that these spots are associated in pairs of opposite magnetic polarity (Fig. 5). They particularly affect magnetic instruments and deflect galvanometers, the increase and decrease of their magnetic activity synchronizing with the eleven-year sunspot cycle. On more than one occasion commercial telegraphic communication has been completely held up by magnetic storms originating in the sun.

These magnetic storms are generally accompanied by extraordinarily beautiful displays of the aurora in

both northern and southern hemispheres (Fig. 6). The wonderful auroral streamers and curtains of colored light are caused by the arrival in the upper regions of the air of electrified particles shot out from sunspots. Their interference with radio reception (Fig. 7) is possibly brought about by the formation of layers, like the Heaviside layer, that reflect the radio waves back to earth. In any case, radio reception is poorest during great sunspot activity and best during minimum sunspot activity.

When a tree is cut down, a section of the trunk shows a number of rings that run concentrically from the center (Fig. 9). As each of these rings represents a year's growth we can tell the age of the tree by counting the number of the rings. Almost any tree will show that the rings are not of equal thickness, which is quite understandable since during dry summers less wood will have been grown than when the tree had plenty of moisture. Thus the tree forms a natural record of the weather experienced during its life time. By studying these rings it has been found that their thickness varies over a period of 11 years, the same period as constitutes the sunspot cycle.

When the sunspots are most numerous, the summers are moist and wet, and so the tree grows more wood and the rings are thicker. Professor A. E. Douglass, Director of the Steward Observatory, Tucson, Arizona, has gone further than this—he has even been able to determine what the weather was like at about the time of the Norman Conquest! He has studied sections of trees used by Indians in the construction of their ancient dwellings. One such tree (Fig. 10), cut down in A.D. 1260, shows by



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Fig. 12. The relative position of the earth, sun, and moon determine when a solar eclipse occurs. Only rarely are the three bodies in a direct line as shown above. It is only when this rare coincidence occurs that an eclipse can take place



Fig. 13. On the left is a small partial eclipse of the sun, and in the center a large partial eclipse. On the right is an annular, or ring, eclipse; here the moon does not cover the sun completely

its rings the variations of climate from that year back to A.D. 1073—truly a remarkable record, the existence and interpretation of which has only been realized quite recently.

If we watch a sunspot day by day we notice that each day it moves a little nearer to the edge of the sun, due to the fact that the sun rotates on its axis, exactly as do the earth and the other planets. Figs. 3 and 4 show how a large spot moves in a few days. The spot shown in Fig. 4 is the same spot as shown in Fig. 3 but in this case the photograph was taken three days later. Whereas in Fig. 3 we see the spots “full in the face,” as it were, in Fig. 4 the spots appear to be more edgewise because in the intervening period they have moved nearer to the limb of the sun. The photograph shows, too, the changes that have taken place during the three days, for a bright bridge has developed across the dark spot and many of the smaller spots have disappeared, covered over by the photosphere. Despite this, the small groups retain their characteristic appearance and

are recognizable as being the same groups as shown in Fig. 3. The movements of sunspots are more clearly shown in the sequence of separate photographs in Fig. 11, where the same group of spots is depicted over a period of five days. The spots are all shown as having moved from right to left.

THE “SYNODIC PERIOD”

The sun rotates on its axis in a period of about $25\frac{1}{3}$ days, but as the earth in the meantime has moved some distance around the sun, the time of rotation (known as the “Synodic period”) appears to us to be about $27\frac{1}{3}$ days. This rotation period applies only to the regions near the sun’s equator, for the regions between the equator and the poles rotate more slowly, some taking two and a half days longer, and those near the poles themselves considerably longer still.

Owing to this rotation of the sun, a sunspot that appears on one edge of the sun is slowly carried across the face in fourteen days, to disappear round the other edge and remain lost

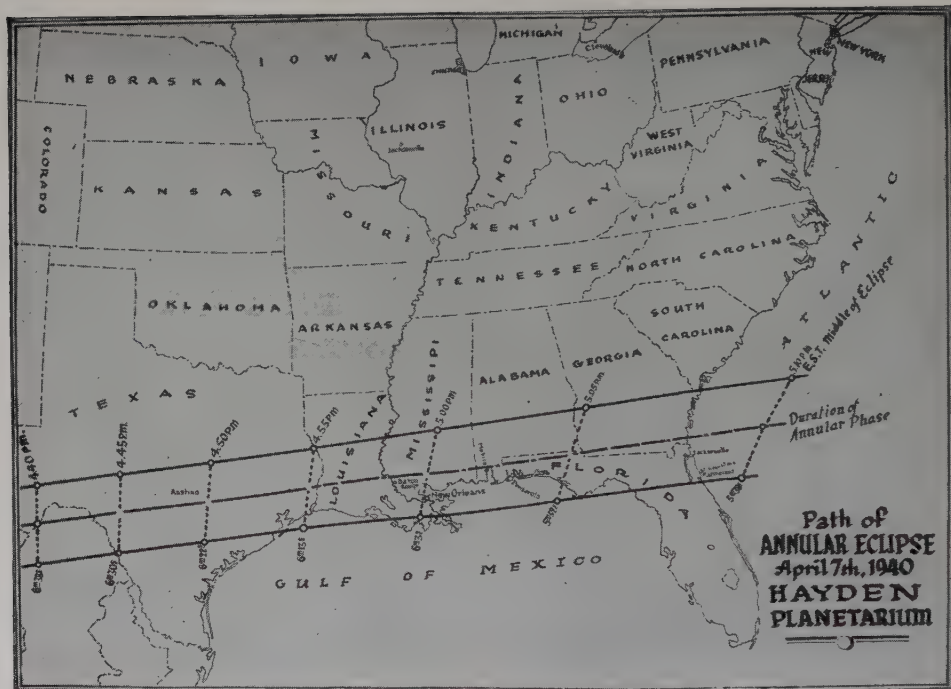


Fig. 14. Line of totality during the eclipse of the sun on April 7, 1940. Within the area indicated in the lower section of the picture the eclipse was total, while outside this line the eclipse was seen as a partial one

to sight for a further fourteen days. It is not always certain, of course, that the same spot will reappear at the expiration of this period, for it may well have been covered up by the photosphere while it is moving across the averted face of the sun.

As it revolves in its orbit around the earth, the moon occasionally comes between the earth and the sun, shutting off the sunlight and causing an eclipse to take place. Although the moon travels completely around the earth every month, it is not always that the three bodies are directly in line—sometimes the moon is too high and sometimes too low, as it were, and no eclipse takes place (Fig. 12). If the moon covers part, but not all of the sun's disc, we have a partial

eclipse, and its extent varies according to the relative positions of the moon and the earth and the position of the observer on the earth. In Fig. 13 the picture on the left shows the partial eclipse of March 28, 1922, in which only a small part of the solar disc was obscured by the moon. The center figure (Fig. 13) shows the partial eclipse of April 8, 1921, an eclipse of greater magnitude; both illustrations depict the maximum phase of the eclipse.

Again, if the moon is at such a distance from the earth at the time of the eclipse that its apparent diameter is less than that of the sun, then an annular (Latin *annulus*, "ring") eclipse occurs. Such an eclipse (Fig. 14) occurred on April 7, 1940, the

path of the annular eclipse crossing northern Mexico, southern Texas, northern Florida, and southern Georgia. Within this path the whole of the sun was covered except for a ring of light that surrounded the moon, causing an annular eclipse.

PARTIAL AND TOTAL ECLIPSES

Although they have some degree of interest, neither partial nor annular eclipses are as interesting or as important as total eclipses. None of the characteristic phenomena of the total eclipse are seen, because in neither partial nor annular eclipses is the whole of the sunlight cut off. The annular eclipse of April 7, 1940, was visible as a partial eclipse over nearly all of North America north of the

path of the annular eclipse, except in Alaska.

During a total eclipse the shadow of the moon falls on the earth and moves over land and sea. Only along the line thus traversed by the shadow does a total eclipse take place (Fig. 15). On either side of this "line of totality" are broad belts that may extend up to 2,000 miles, and from places within these areas only a partial eclipse will be seen. Actually the line of totality is never more than 167 miles in width, the duration of a total eclipse never being longer than seven minutes and thirty seconds under the most favorable conditions.

Arising out of these factors we see that an eclipse of the sun is to a certain extent a local phenomenon—an

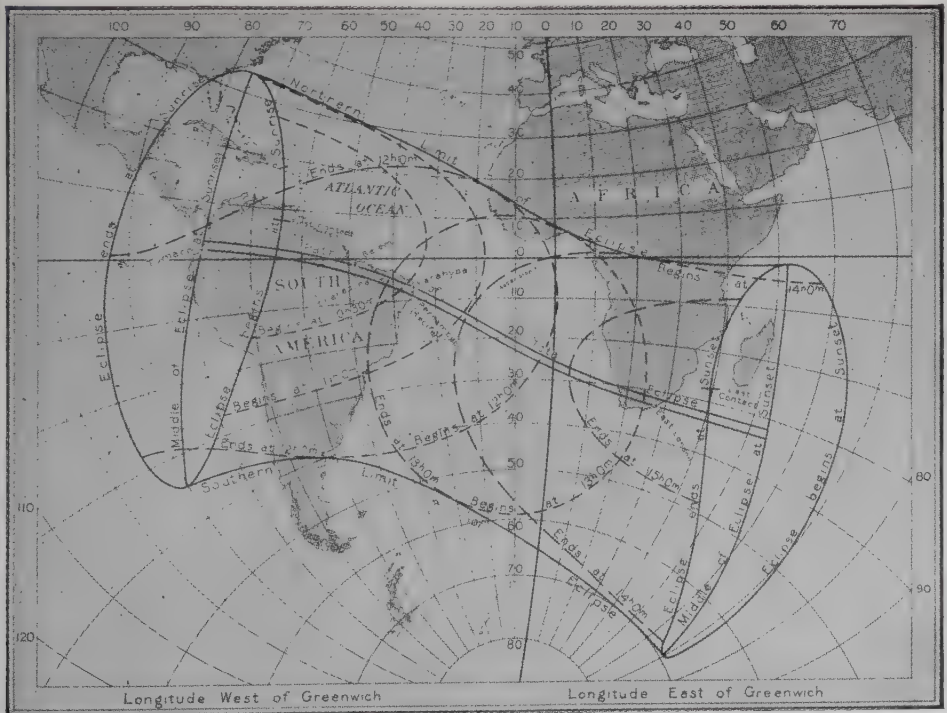


Fig. 15. A map of the total eclipse of the sun of October 1, 1940

eclipse that may be total in Canada may only be partial in the United States, and to an even less degree in Mexico, the location of the line of totality being the determining factor. The next total eclipse of the sun visible in North America will occur on July 9, 1945, the path of totality crossing Canada. In the United States this will be a partial eclipse.

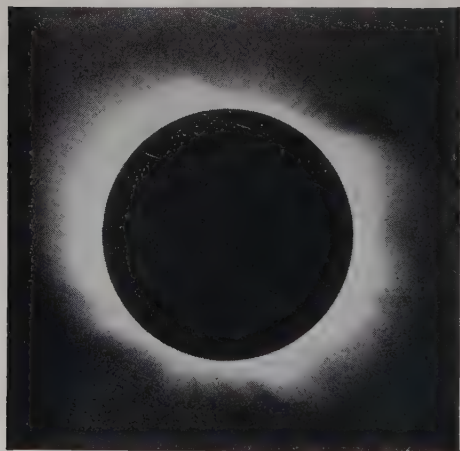


Fig. 16. The corona and solar plumes, seen only at the time of total eclipse

Eclipses have been recorded carefully from the earliest times, and so well known are the movements of the heavenly bodies that the calculation of eclipses is a very precise matter. The earliest mention of a solar eclipse—for which the date has been worked out with a high degree of probable accuracy—is recorded in an ancient Chinese manuscript. Here it is picturesquely stated that “on the first day of the last month of autumn, the sun and moon did not meet harmoniously in Fang.” Fang was part of the heavens now marked by four stars of the constellation of Scorpius. Investigations show that this inharmonious meeting of the sun and moon without

doubt refers to the solar eclipse that occurred on October 22, 2137 B.C.

We can date with unimpeachable accuracy eclipses of the past, and many eclipses in history have been identified and definitely dated. We know, for instance, that an eclipse occurred at Ur at 11 a.m. on March 8, 2283 B.C., and that the eclipse at Ithaca, mentioned in Homer’s *Odyssey*, occurred at 11.41 a.m. on April 10, 1178 B.C. From the calculation (made in 1925) of this eclipse it was attempted to calculate the date of the fall of the city of Troy, which most probably occurred in the year 1200 B.C.

Fig. 15 shows the line of totality, beginning in Colombia, South America, crossing Brazil, the Atlantic Ocean, and South Africa, of the eclipse of October 1, 1940.

During the brief period of an eclipse when all direct sunlight is cut off from the earth, the brighter stars and planets are visible in the sky even though it may be midday. “There was such an eclipse of the sun,” wrote Diodorus Siculus who lived in the last century before Christ, describing the eclipse of August 15, 310 B.C., which, of course, he did not himself observe, “that the day wholly put on the appearance of night, and the stars were seen in all parts of the sky.”

At the instant of totality, too, there are seen pearly streamers of light surrounding the interposed body of the moon (Fig. 16). This is the corona (Latin: “crown”) that, although always present around the sun, is invisible at other times because of the overpowering brilliance of direct sunlight. The corona varies in appearance and extent at different eclipses, the rays being affected by the same periodic ebb and flow of solar ac-

tivity that causes the sunspot cycle.

THE CORONA

The corona does not form part of the sun's surface, and it may not share in its rotation. Of eruptive and electrical origin, it is probably due to streams of atoms and electrified particles that are shot out from the sun with tremendous velocity. The arrangement of these particles must be of inconceivable tenuity, and the particles themselves must be in a perpetual state of movement under the opposing forces of attraction and repulsion. The arrangement is probably due to some electro-magnetic action,

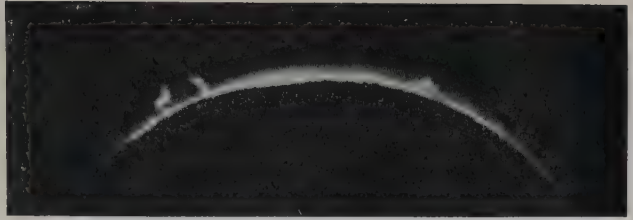


Fig. 17. A prominence during an eclipse. The uneven edge of the moon, due to the lunar mountains, is clearly seen

a similar streaming effect having been reproduced in the laboratory by means of electrical discharges in partial vacua (spaces almost devoid of matter).

During an eclipse there are visible, around the dark edge of the moon, vivid flamelike projections known as prominences that shoot out from the chromosphere, or solar atmosphere (Figs. 17-20). Although at one time these could only be seen during an eclipse, the application of an instrument known as the spectrohelioscope, invented by Dr. G. E. Hale, of the Mount Wilson Observatory, made it possible to see them at other times. We shall deal later with the spectroscope, the instrument upon which the spectrohelioscope is based, and it will be sufficient here to remark that this invaluable instrument was introduced in 1860 by Kirchhoff.

In 1890, preceding the invention of the spectrohelioscope, it was found possible to study the prominences



Fig. 18. A solar prominence and the corona during an eclipse

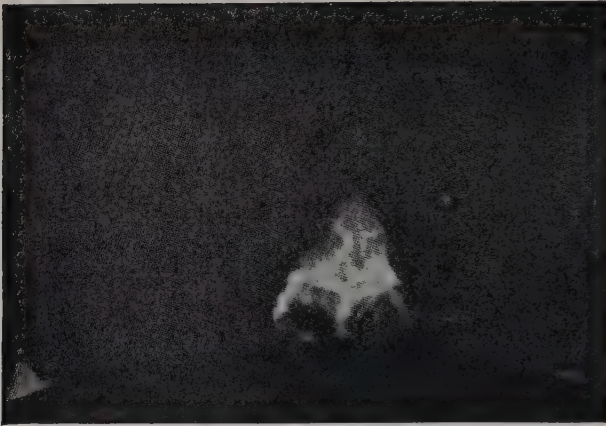


Fig. 19. A huge cloud of hydrogen gas being ejected from the sun at a velocity of hundreds of miles a second. A comparison with Fig. 20 will show the immense speed at which the cloud travels

photographically by using only certain light rays—such as those given out by calcium—and eliminating the unwanted rays. Observations of this kind are made possible by the spectroheliograph, also invented by Dr. Hale. The spectroheliograph, which was also developed independently by H. Deslandres, a French astronomer, will be described later, in our chapter on Light.

The prominences just mentioned consist of enormous masses of gas—particularly of hydrogen and calcium—ejected from sunspots under great pressure. Prominences of the flame type “flicker” like the flames of our fire-sides, and in some cases rise to extraordinary heights above the sun’s surface, ejected at speeds of hundreds of thousands of miles an

hour (Figs. 17, 19 and 20). Some prominences are cloudlike in appearance and seem rather more permanent than those of the flame type, sometimes lasting for several days. They are generally connected with the sun’s surface by thin columns of gas, which bear some resemblance to the “funnel” of a waterspout.

From our brief account of the sun it is evident that it provides science with one of its greatest mysteries and marvels. Man has

learned a great deal about it, but there is yet much to be learned, and much that will probably never be known. For instance, it is calculated that the temperature at the sun’s center must be in the neighborhood of $40,000,000^{\circ}\text{C.}$ —or about $70,000,000^{\circ}\text{F.}$ —and its pressure must be thousands of tons to the square inch. We cannot conceive how matter will



Fig. 20. The hydrogen cloud shown in Fig. 19, having risen to a height of 350,000 miles in less than an hour

behave under such conditions—even atoms must be broken down, constituting a state of things of which we neither have nor probably ever will have experience.

In the attempt to solve the mysteries of science, particular importance is

ant of all is the determination of the earth's distance from the sun, for on an accurate determination of this factor depend many other measurements. For example, unless the sun's distance is determined accurately we cannot know the exact radius of the

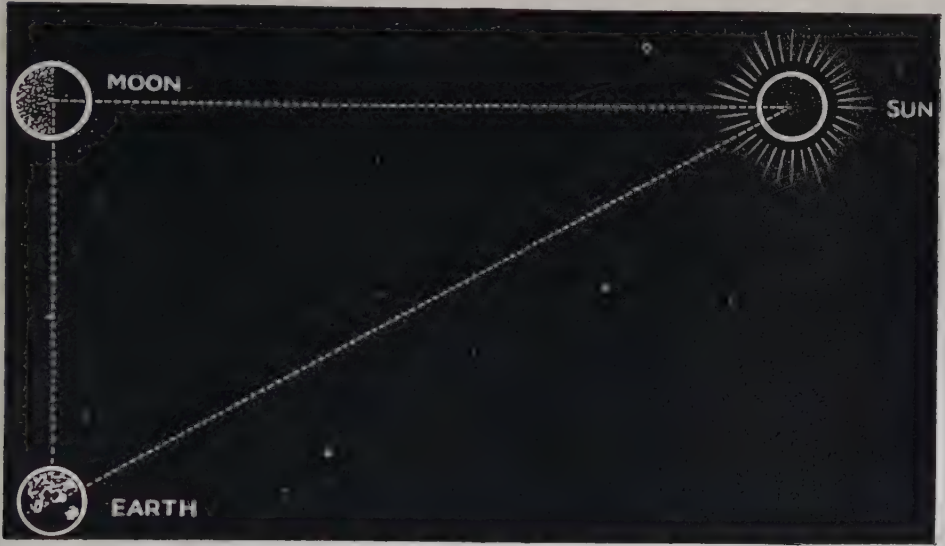


Fig. 21. How Aristarchus tried to measure the distance of the sun. When the moon is exactly half illuminated, the angle between earth, moon, and sun is a right angle

attached in every branch to determining the bases from which subsequent calculations or deductions are made. Where these fundamental constants, as they are called, cannot be determined with sufficient accuracy at the outset, the endeavor is continually to revise the adopted standards with a view to increasing accuracy in the light of more recent knowledge.

In astronomy it is always desirable to obtain a greater refinement in regard to the measurements of the heavenly bodies—particularly of the masses of the planets and of the moon—and of the various motions of the earth's axis. Perhaps the most import-

orbit of the earth. Any error in this repeats itself in many ways—such as in calculating the radii of the orbits of all the other planets. As a rule such calculations involve computations by cube, so that even a small error becomes enormously multiplied in the final result.

Work on the problem of the sun's distance must be done with a degree of accuracy that would enable scientists to measure exactly the angle subtended by a penny held at a distance of 2,000 ft. from the eye of the observer. The angle thus to be measured, which is called the "solar parallax," is that which the earth's equatorial



Fig. 22. Position of Mars in relation to other stars as seen from Paris (left) and Cayenne (right)

radius subtends at the distance of the sun.

THE MEANING OF PARALLAX

The astronomers of old often made ingenious attempts to solve the problem of exactly how far distant the sun is from the earth and although their efforts were absurdly inaccurate, some of the methods they employed were scientifically sound. The earliest effort was made in the third century B.C. by Aristarchus of Samos, who endeavored to find how many times

greater was the sun's distance from the earth than that of the moon from the earth. Fig. 21 shows how he attempted to do this.

When the moon is exactly half illuminated—that is to say, when it is in the first or last quarter—the angle at the moon between the observer on the earth and the sun is a right angle. If the sun were only at the same relative distance from the earth as shown in the diagram, the angle sun, earth, moon would be 60° . It follows the nearer the sun comes to the earth, the smaller will this angle be.

Geometrically sound, the method is quite impracticable, for it is impossible to determine the instant when the moon is exactly half illuminated, and a very slight error here falsifies the result. Aristarchus found that the angle formed by the sun and moon with the earth was 87° when the moon was half illuminated, and calculated therefore that the sun was eighteen to twenty times as far away



Fig. 23. Effect of parallax. (Left) what you see with left eye closed and (right) with right eye closed

from the earth as the moon. By this measurement, Aristarchus placed the sun at a distance of about 4,500,000 miles, or about twenty times less than the actual distance.

Of the several methods of measuring the sun's distance, one of the most important is that based on a principle

The distance that the object appears to move is as the width between our eyes would appear to anyone who looked at us from the position occupied by the object in question. This apparent movement of an object is called "parallax," a Greek word meaning "shift." Obviously, if we can deter-

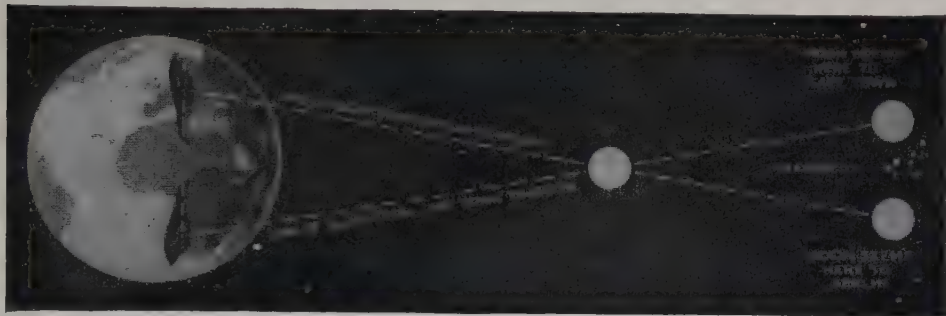


Fig. 24. How the position of an object in relationship to a third fixed point appears to alter when it is viewed from two different positions. The apparent movement is called parallax

employed in 1673 by G. D. Cassini. This noted Italian astronomer attempted to solve the problem by first measuring the distance of Mars. This depends on measuring the change in the apparent position of a distant object as seen from two different positions. For example, look with the right eye only at an object close at hand and note its position with regard to the distant background. Now cover the right eye and without moving your position look at the same object with the left eye. The object seems to have moved to the right, by an amount that depends on the distance of the object from the eye (Fig. 23). The apparent shift in position is due to the fact that our eyes are about 3 in. apart and therefore the point from which we see the object with the right eye is not quite the same as that from which we view it with the left eye.

mine the parallax of a heavenly body we shall be able to ascertain its distance. This is based on the fact that the greater the distance of the object the smaller will be the parallax.

FINDING THE PARALLAX

There is a limit to the parallax that can be seen by alternatively viewing with each eye so that it becomes necessary to increase this "base line" for more distant objects.

This can be done quite easily by noticing the position of the distant object in regard to some object behind it and at a greater distance, and then walking a few feet to the right or left, from which position a parallax may be obtained (Fig. 24). Another way is to station a second observer at the other point and have each observer measure the angle subtended by the distant object.

This is precisely what was done in measuring the distance to Mars. By arrangement, Cassini at Paris, and Richer at Cayenne in French Guiana, simultaneously measured the angle subtended by Mars against a background of distant stars, the two observers being separated by the enormous base line of 4,500 miles. This resulted in the position of Mars, in regard to the stars near it, appearing slightly different to each observer (Fig. 22). From the measurements thus obtained, they were able to obtain the two angles at the base of a triangle joining Paris and Cayenne to each other, and each of them to the planet (Fig. 25). The resulting triangle was easily measured and the distance of Mars was determined. Then by applying one of Kepler's laws of motion, it was possible to calculate the distance of the sun from the earth. Cassini's figure gave a parallax of 9.5 seconds, placing the sun's distance at 87,000,000 miles, a result that was only some 5,900,000 miles less than the mean distance. Though 5,900,000 seems immense, this was relatively not a bad approximation.

Later a more accurate method of measuring the distance to the sun was devised, which depended upon a

transit of Venus. It is only on rare occasions, however, that this method can be applied, for Venus passes exactly between the earth and the sun only twice in about a century. The last transit of Venus occurred in 1882, and the next will be in 2004. Since Venus approaches nearer to the earth than any other of the major planets, the shift as it crosses the disc of the sun, observed from widely separated points on the earth, is considerable and can be measured, thus providing data from which the distance to the sun can be calculated.

DISCOVERY OF EROS

The problem of measuring the sun's distance was considerably simplified when, in 1898, the minor planet Eros was discovered. We shall describe the minor planets later, and in the meantime it will be sufficient for us to say that Eros is a very small body, probably not more than 20 miles in diameter. As seen in the telescope, there was nothing to lead its discoverer (Witt of Berlin) to suppose that he had found an object that differed in any way from the hundreds of other known minor planets, but later it was found that the discovery was of the highest importance. The particular



Fig. 25. How the earth is used to determine the distance of a planet. From A, the position of Mars appears to be at D, from B at C. Taking a triangle from the base line on the earth, A B, the exact distance of the planet can be calculated without difficulty

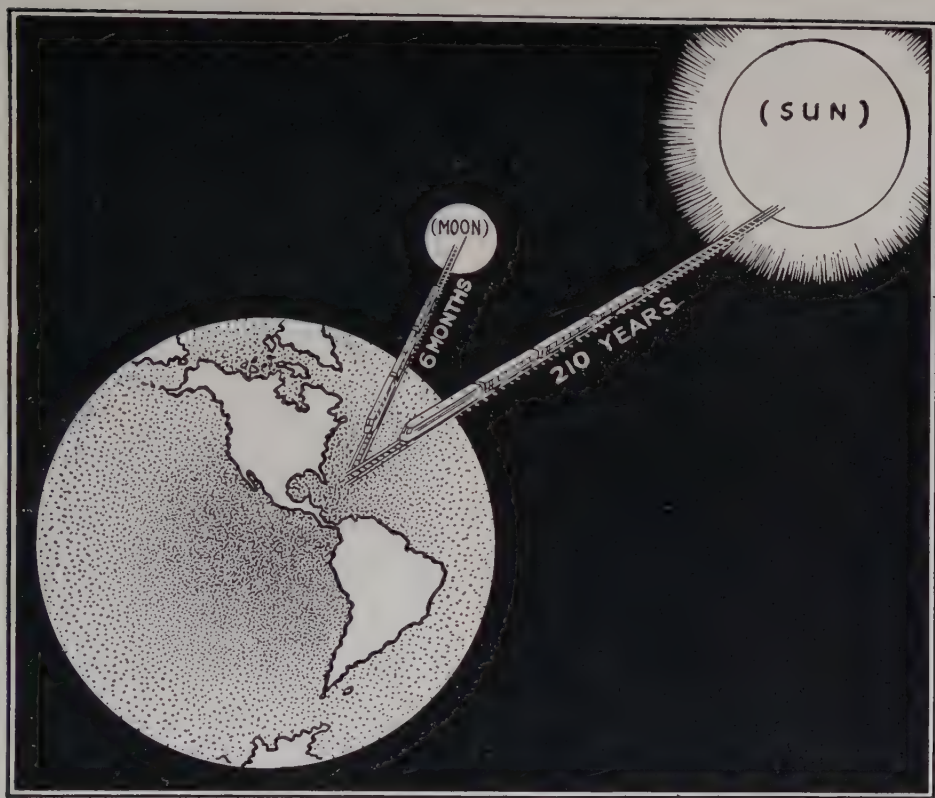


Fig. 26. How enormous are the distances separating the earth from the sun and moon, can be judged from the fact that the fastest American train would take six months to reach the moon and 210 years to reach the sun

fact of interest about this planet is that it moves in an orbit that is highly eccentric—so much so that on certain occasions the planet comes to within less than 14,000,000 miles of the earth. As Mars can never be nearer to us than about 35,000,000 miles in the most favorable circumstances, and Venus never nearer than 26,000,000 miles, little Eros had at the time of its discovery the distinction of being, with the exception of the moon, our closest celestial neighbor whose orbit was accurately known from scientific calculations.

Such a near approach as that of Eros gives us a much better opportunity to determine its parallax than in the case of Mars or Venus. In 1900 it was arranged to observe the position of Eros from many widely separated observatories, and to reduce the resulting observations to a common form. The work occupied ten years and gave as a result a solar parallax of 8.80 seconds, indicating an average distance of the earth from the sun of approximately 92,900,000 miles.

Let us see if we can get some idea of what this distance of 93,000,000

miles means. A million is one thousand and thousand—1,000,000. What this implies may be realized better by the fact that a clock that ticks once a second would require 1 week, 4 days, 14 hours (278 hours), to tick a million times. Incidentally, a billion is one thousand million (1,000,000,000), which the clock would require nearly 32 years to tick away.

DISTANCE TO THE SUN

We know that the "Twentieth Century Limited" makes the journey from New York to Chicago (875 miles) in about sixteen hours. If we could lay a railway to the moon and arrange for the train to run day and night, without stopping for coal or water, it would reach the moon in six months (Fig. 26). For the same train to reach the sun would require over 200 years—so that had George Washington been able to buy a ticket he would not yet have arrived at his destination!

Yet another illustration may be given to bring home some idea of the enormous distance we are consider-

ing. Although when we burn our finger with a cigarette we seem to feel pain at the same instant, actually this is not the case, for an appreciable fraction of time elapses before the record of the sensation reaches the brain. A shock of this kind is communicated by our nerve impulses at a speed of about 100 ft. a second, or 1,637 miles a day. If we could imagine a young child with an arm so long that he could reach up and touch the sun with his fingers, he would have time to grow to a ripe old age and die, before the sensation of pain could be communicated from his fingers to his brain. That is to say, he would not live long enough to feel the pain of this gigantic burn. If we consider this fact carefully we should be able to form some faint conception of astronomical distances.

We now leave the sun, the source whence the earth derives its light and heat, and upon which all its forms of life depend, to turn, in the next chapter, to a consideration of the lifeless moon, the earth's nearest neighbor in space.

CHAPTER 2

THE MOON

ALTHOUGH the sun and the moon both *seem* to have the same diameter when seen in the sky, this is only an illusion. We have seen that the sun is an enormous body a great distance away from the earth. On the other hand the moon is comparatively small, having a diameter of only about 2,160 miles—about one-fourth that of the earth. It is only about 239,000 miles distant, and is, in fact, the nearest of all the heavenly bodies, being very close to the earth as astronomical distances go. The moon is said to be the earth's satellite, a word coming from the Latin *satelles*, an attendant.

Exactly as the earth revolves around the sun in a year, so the moon revolves around the earth in a "moonth" or month—or, to be strictly accurate, in 27 days 7 hr. 43 min. 14 sec. Its motion from west to east must not be confused with the daily motion from east to west of all the heavenly bodies. This latter motion arises from the rotation of the earth on its axis and causes the sun, moon, and stars to rise and set.

We can see only one hemisphere of the moon. No one has ever seen the other "side" of our satellite—what it would show is one of the great mysteries of astronomy. To explain more clearly why it is that the moon always presents the same face to us we may take the example of a horse that canters around the ring at a circus. The ringmaster is in the position of an inhabitant of the earth, for although the horse is making a complete revolution around him he never

sees its off-side. What may appear to him to be an all-white horse may, for all he can tell, have a large, dark patch on the off-side. On the other hand, a spectator outside the ring will see both sides of the horse, exactly as anyone standing on one of the outer planets would see both sides of the moon.

The "phases," or variations in the appearance, of the moon—crescent, quarter, full, and so on—greatly troubled the ancients. In fact, to explain them correctly would trouble many intelligent people today. Yet the explanation is quite simple. The Babylonians even supposed that our satellite had a bright and a dark side, and that as it moved through the sky it gradually turned the bright side towards the earth, until at full moon, they thought, the whole of it was seen. Of course, this is not the correct explanation, for as in the case of the earth, the moon is a completely dark body and is probably composed of the same materials. Indeed, as we shall shortly see, it is believed by some astronomers that once the moon actually was part of the earth, from which it was violently torn off to form a separate and distinct body in very remote times.

The moon has no illuminating power of its own, such as the sun possesses. It shines by reflecting sunlight, and its phases are merely caused by the different positions from which we on the earth view the illuminated portion of the moon's surface. Fig. 1 is an artist's drawing which will make this clear.



Fig. 1. The moon in its orbit round the earth, showing how the phases are caused

PHASES OF THE MOON

When we first see the "new" moon in the west it appears as a thin crescent, that gradually increases in size until it is "half" full, or in the "first quarter" as it is called (Fig. 2). The illuminated portion grows night by night (Fig. 3) until it becomes three-quarters illuminated, when it is known as "gibbous." Ultimately the whole of the hemisphere that is turned towards us is illuminated, when the moon is said to be "full" (Fig. 4). It is then roughly opposite to the sun, so the sun, earth, and moon lie in one plane. The three bodies seldom lie in an exactly straight line. Whenever they do the earth's shadow causes an eclipse of the moon. Thereafter, the reverse process sets in and the illuminated portion commences to decrease in size (Fig. 5) as the moon works its way towards the sun. It passes successively through the gibbous, last quarter, and crescent stages, until it moves between the earth and the sun, to start the cycle again as a new crescent moon.

As the moon grows from new to full it is said to be "waxing," and after full, it is said to be "waning." It should be mentioned that the waning crescent is turned in the opposite direction from that of the waxing crescent. The curve of the crescent always points to the setting or rising sun—as though the moon were a bow shooting an arrow at the sun (Fig. 6). That some people do not realize this is evident from the fact that artists have painted pictures (from their vast stock of imagination) in which the new moon appears with the crescent pointing in many directions quite impossible of attainment in the actual physical state.

THE MAN IN THE MOON

Everyone has heard of "the man in the moon," and from very early times the dark markings to be seen with the naked eye have been likened to a man's face. Indeed, as a popular belief the legend that the man was put there for gathering sticks on a Sunday goes back to very ancient times. The "lady in the moon" is a more modern fancy and can best be seen when the moon is about three-quarters full. Those with greater imagination see other figures. These

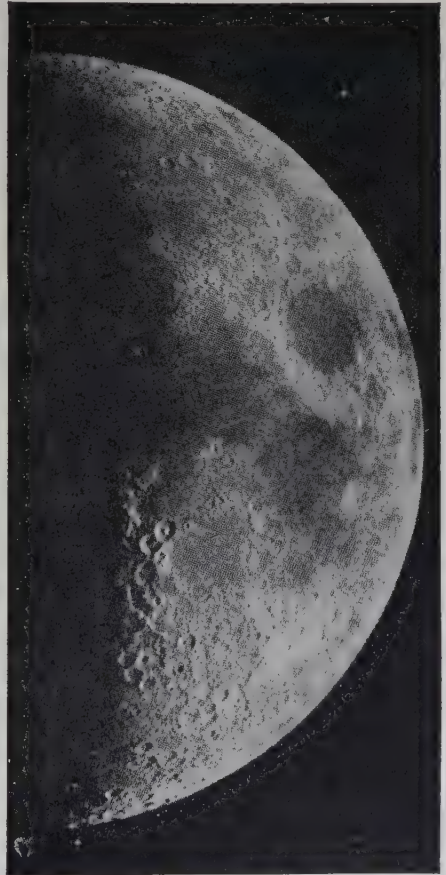


Fig. 2. How the new moon looks when it is a crescent, 5 days 23 hours old



Fig. 3. The nine days old moon

include the "girl reading a book," "the crab," and "the donkey" (Fig. 8). Some have even discovered a "French poodle" that sits on his haunches and is correctly trimmed even to a distinct "pom-pom" at the end of his tail!

At one time the dusky markings that help to form the pictures we have just mentioned were supposed to be the reflection from the mirror-like surface of the moon of the oceans and continents of the earth. Looking at the moon with his telescope (in

1610), Galileo saw for the first time that the markings were actual configurations on the moon itself. He came to the conclusion that the large dark patches were lunar seas, and this is why they came to be called by the Latin name *maria*. To each of these "seas" was given a name that was thought to be in keeping with its appearance, such as *Mare Serenitatis*, "the Sea of Serenity," *Mare Imbrium*, "the Sea of Showers," and so on. These so-called seas have a great expanse, *Mare Serenitatis*, for example, being 433 miles from north to south, and 424 miles from east to west. *Mare Imbrium* measures 750 miles by 700 miles, and covers the huge surface area of 340,000 square miles.

THE MOON THROUGH A TELESCOPE

When seen through a telescope (Figs. 2-5), the markings of the moon



Fig. 4. The moon just past the full. Notice the bright "rays" that can be seen radiating from the craters

certainly do appear to be smooth and ocean-like, and we do not wonder that the astronomers of three centuries ago supposed them to be seas. In the light of later knowledge, however, we know that there is no water on the moon and that although the *maria* may have been lunar seas at one time, it is certain that today they are nothing but great desolate and lifeless plains.

A pair of field glasses is sufficient to show us that there are numerous ring-like objects scattered over the surface of the moon, and even a small telescope shows these objects to be very numerous (Figs. 2 and 3). These strange objects are the famous "crater rings," many thousands in number and varying in size all the way up to the great Grimaldi, 150 miles in diameter. Even taking into consideration the increased height of the lunar mountains—to which we shall refer shortly—it has been calculated that if a person were to stand in the center of one of the great lunar plains, the mountains forming the walls of these plains would be far below the horizon, owing to the considerable curvature of the moon's surface.

Each crater is named, some being called after famous astronomers such as Eratosthenes, Copernicus, and Tycho; others after ancient philosophers, as Plato and Aristotle. Over



Fig. 5. The illuminated area of the moon at $16\frac{1}{2}$ days. Compared with Fig. 4, it is markedly decreasing

30,000 of these craters have been recorded carefully on maps, down to the smallest detail—even to cracks and rills that cross them. Indeed, it has been said with truth that we know the surface of the moon better than we know some parts of the surface of the earth. There are parts of Africa and Brazil that have never been explored or mapped, and on the other hand, on any clear night our large telescopes enable us to study the moon's surface as from an airplane flying at a height of 240 miles above it. From this distance any object approximately the size of the American Museum of Natural History in New York City would be visible only as a tiny dot. With the new 200-in. telescope, on Mount Palomar, we shall



Fig. 6. The curve of the crescent moon always points towards the sun (shown here in outline on the right below the horizon) because the crescent is, of course, a part of the side lit up by the sun

be able to see objects considerably smaller.

In addition to the lunar craters there are several magnificent mountain ranges, some of which are named after similar ranges on the earth—the Alps, Caucasus, Apennines, Carpathians, and many of the famous ranges known the world over.

MOUNTAINS ON THE MOON

It is easily possible to determine the heights of the lunar mountains by measuring the length of the shadows they cast, exactly as the height of a flagstaff or mast of a radio aerial can be worked out by simple trigonometry. It has been found that though none of the lunar mountains are as high as Mount Everest, their height in relation to the moon's size is far greater than the earth's mountains in

relation to the earth's size. As we have seen, the diameter of the moon is about one-fourth that of the earth—actually 2,160 as compared with the earth's 8,000 miles—and its mass about one-eightieth that of the earth. Despite this we find that some of the lunar mountains nearly equal the height of our Himalayas. The Döerfel Mountains rise to a height of 26,691 ft.; the walls of the great crater Newton, to 23,853 ft.; and the central peak of the crater Eratosthenes, to 15,750 ft. Compared with these, our highest mountain, Mount Everest, scales 29,002 ft., Mount Blanc, 15,870 ft., and the Snowdon group in Wales, a mere 3,500 ft. Comparative size of earth and lunar mountains is seen in Fig. 9.

A more striking way of showing that the lunar mountains are much higher comparatively than the ter-

restrial mountains is to work out their relationship to the diameter. Thus, the height of Mount Everest, say, 29,002 ft., is equivalent to $\frac{1}{1140}$ of the diameter of the earth, but the highest lunar ranges represent an equivalent of $\frac{1}{470}$ of the lunar diameter.

Here and there the lunar surface is crossed by clefts or rills, almost like the crevasses of the Alpine glaciers (Fig. 10). These cracks often extend for hundreds of miles, and are from half a mile to two miles in width, and of unknown depth. These chasms on the lunar surface can be compared with nothing terrestrial. Their origin is a mystery unsolved by science.

THE MYSTERIOUS BRIGHT RAYS

Even more mysterious are the bright rays that radiate from some of



Fig. 7. Crater Copernicus is 56 miles wide

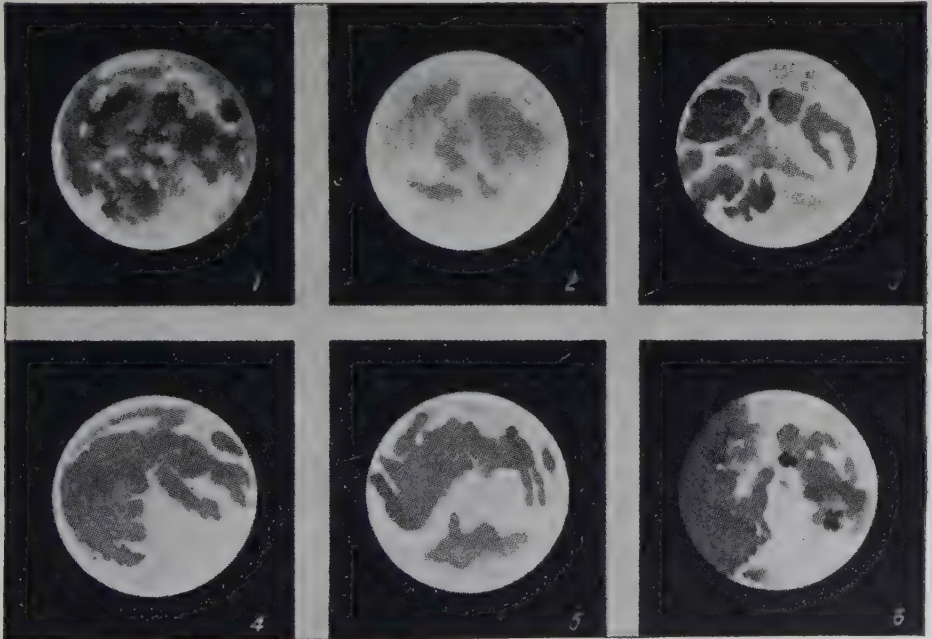


Fig. 8. The figures popularly seen on the moon (1) The moon as an astronomer sees it through a telescope. (2) The man in the moon. (3) Crab. (4) Girl reading book. (5) Donkey. (6) Lady. The figures are exaggerated to make them clearer

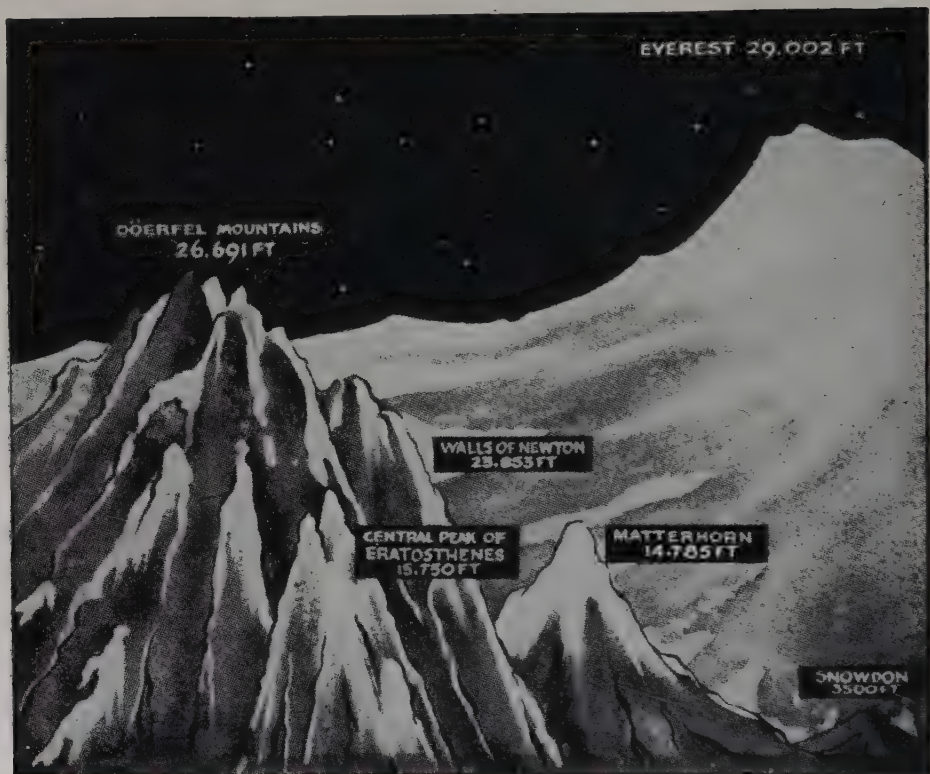


Fig. 9. Comparative heights of the mountains on the moon and those on the earth. The Dörfel mountains on the moon are nearly as high as the Himalayas

the larger craters—such as Tycho, Copernicus, Eratosthenes, Grimaldi, and Kepler—unusually well shown in Fig. 4 on page 26. Some are to be seen almost at any time, but others are seen only when the moon is full. Why this should be we do not know. In 1900 Professor William H. Pickering, of Harvard University, established an observatory in Jamaica to study the details of the lunar surface. He believed that alterations were taking place in the shape of some of the formations and particularly in the large walled plain called Plato. He actually came to the conclusion that the moon is not a dead world, that it has an atmosphere, and that some of

the volcanoes are still active, giving out clouds and dense gases. He believed that the strange white markings were due to hoar frost derived from frozen water vapor that had never been in a liquid or free flowing condition.

We know now, however, that the moon has neither atmosphere nor water, and in consequence fog, haze, and clouds are unknown. The absence of air and water precludes the existence of any form of life, as we understand the word. Vegetation is unknown. There is no definite sign even of the lowest forms of life. All that exists is a lifeless wilderness of mountain ranges and innumerable crater

rings—a barren world. Even if the existence of air and water could be proved, the extremes of temperature would make life as we know it impossible, for these vary from about 250° F. to more than 200° below zero—the scorching sun of the lunar day and the intense cold of the lunar night. The moon affords a striking object lesson of the fate that awaits the earth when in the course of time it, too, will have lost its water and its atmosphere, without which essential features life will no longer be able to exist.

Both Galileo (1564–1642) and Kepler (1571–1630) suggested that the tides are caused by the action of the sun and the moon. Sir Isaac Newton (1642–1727) placed the matter on a sound basis when he investigated it, and the mathematical theory was completed by Laplace (1749–1827). The moon plays the more important part in causing the tides, thus keeping the waters in our oceans free from stagnation. The sun also helps in this direction, but although it is infinitely larger than the moon, its influence is considerably less because its distance is so much greater, and the effect of gravity, which is the force concerned, is inversely proportional to the square of the distance. This may sound rather technical, but we shall explain it at greater length in our section concerning the earth. Actually the pull of the moon on the water of the ocean is about three times as strong as that of the sun.

WHY THE MOON CAUSES TIDES

Now, how do the moon and the sun cause tides? They do so because they act like huge magnets, pulling on the earth (Fig. 11). The solid land is not visibly affected by this pull—it can

move only as a whole—but the water on its surface is more mobile and can move independently. In other words, water readily assumes a new shape, while land does not. As a result, the water, responding to the attraction of the moon's gravitational pull, is piled up in a heap. Twice every 24 hours throughout the moon's revolution around the earth the tides ebb and flow—that is to say, twice the sea leaves the shore and twice it comes back.

We have said that the land is not visibly affected by this pull of the moon and sun. Nevertheless, the land does rise up like the sea at the time of the tides, and a seismograph—or



Fig. 10. In the top right hand corner is the great walled plain, Albatengius, 80 miles across, with its mountain barrier 14,000 feet high. Numerous craters are seen below it

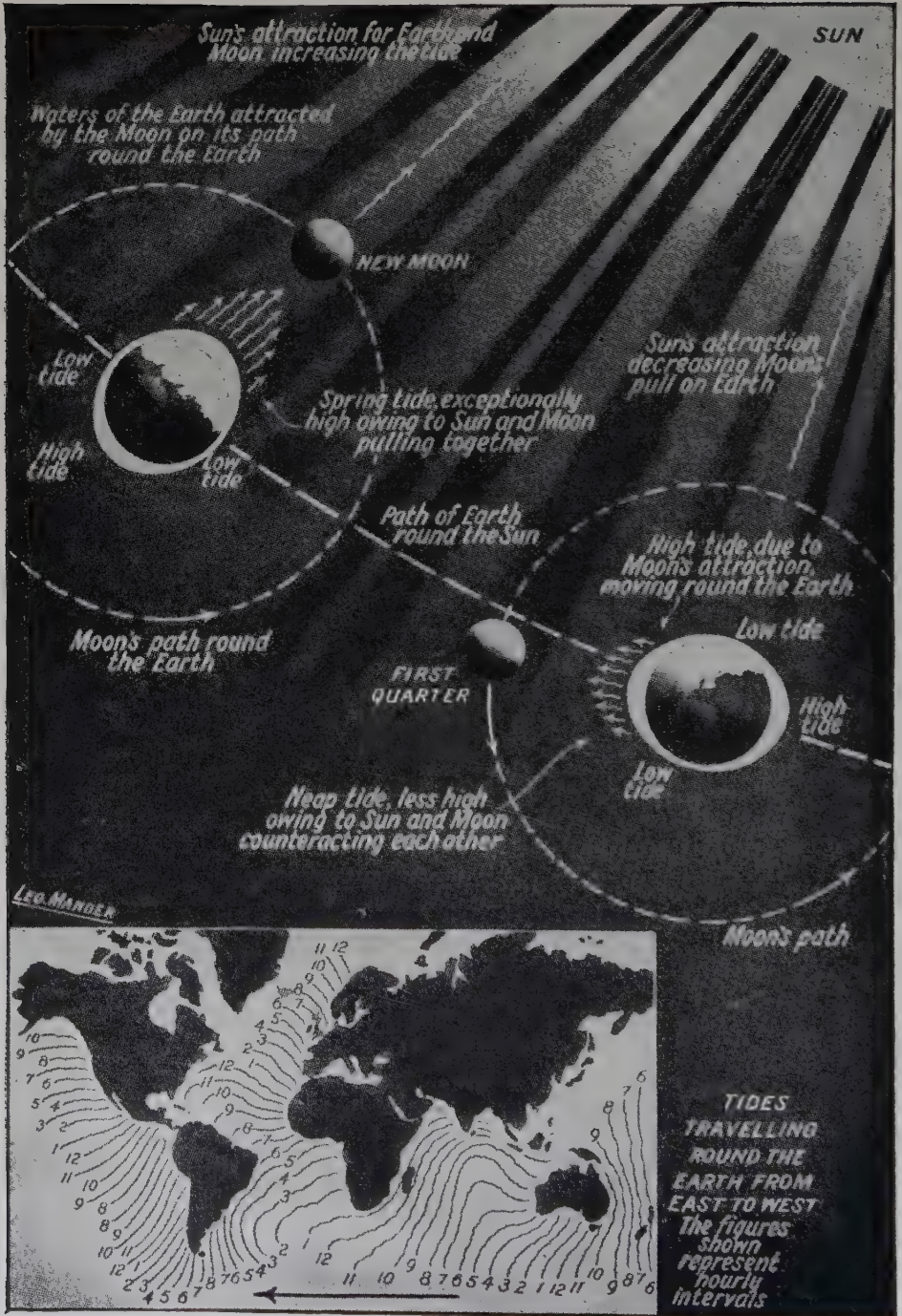


Fig. 11. How tides are caused by the gravitational effect of the sun and moon

earthquake-recording instrument — is sufficiently delicate to record these minute tidal waves in the land.

We often hear the terms “spring tide” or “neap tide.” Spring tides occur when the moon, the sun, and the earth are in line and the two former exert a combined pull on the waters of the oceans (Fig. 11). These tides are the most marked of all—that is, at these times the high tides are highest and the low tides lowest—but the name “spring tide” is somewhat misleading, since such tides occur twice every month throughout the year, when the moon is new and when it is full. Neap tides, the opposite to spring tides, occur when the moon and the sun are pulling the waters in different directions—that is to say, when the moon is either at the first or the last quarter. The result is that at these times there is least difference between high and low tide levels.

Some very interesting speculations resulted from an investigation into the tides, made by the late Sir George H. Darwin. He suggested that the constant tidal wave raised throughout the ages must be acting as a giant brake on the rotating earth, slowing it down and ultimately increasing the length of the day until in time it will be as long as the lunar month. If this theory is correct, the amount by which the earth is slowed down must be infinitesimal, for so far as we know the length of the day has not increased even by a fraction during the history of men. On the other hand, we must remember that it is only during the last few hundred years that the accuracy of observation has been such as would enable the discrepancy to be detected. Even then, observations over a period of tens of thousands of

years would be necessary to detect the minute quantity involved. A period of about 50,000,000,000 years is calculated to be the time required for the earth's rotation period to slow down until equal to the lunar month.

Sir George proved that the distance of the moon from the earth is increasing, and that therefore—in accordance with Kepler's laws of motion—its period of revolution is necessarily becoming longer. This being so, the time will come eventually when the length of the day and the month will coincide—both will last for 55 of our present days, the moon revolving around the earth in the same length of time as is required by the earth to rotate on its axis. Then a reverse movement will set in, and the moon will again draw close to the earth until it reaches what is known as “Roche's limit,” situated about 12,000 miles distant from the earth. When that distance is reached enormous lunar “tides” will be raised by the earth, and the moon will be shattered to fragments. A ring of tiny satellites will be formed—similar to those that are to be seen revolving around Saturn, as will be discussed later in the chapter on Planets.

So much for the future. Let us now look into the past, when the earth was rotating on its axis in a very much shorter period than at present—probably about four or five hours. At that time the moon must have been nearer to the earth than it is today, and was probably revolving around the earth in a period that coincided with the rotation period of the earth.

Looking back still further, in time, probably there was a time when the earth and the moon, in a semigaseous or plastic state, were so close as to be in contact with one another. Before

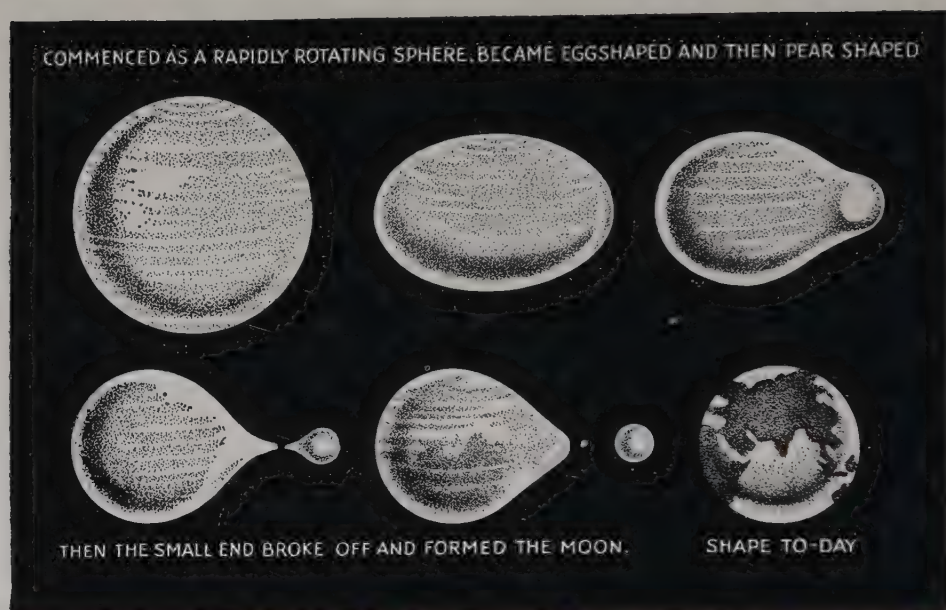


Fig. 12. One theory of how the moon was formed. During the plastic period in the earth's history part of it split off centrifugally to form a separate body—the moon

this, again, the two may have formed a single body, the rapid period of rotation of which, and the consequent enormous tides, caused the moon to split off from the earth. This theory, represented diagrammatically in Fig. 12, suggests that at this time the denser materials of this earth-moon body collected at the lower levels, while the lighter materials distributed themselves uniformly over the surface. To-day, there is a conspicuous absence of these lighter materials in one portion of the earth, from which it is suggested that the moon was torn off. The mass of material that formerly covered that part of the earth where there are now no continents would correspond in density to that of the moon. In other words the continents of that part of the earth now occupied by the Pacific Ocean, are to be seen high in the heavens, a quarter of a

million miles distant and still slowly receding from the earth—the parent body!

ECLIPSE OF THE MOON

An eclipse of the moon is caused when the moon passes through the long shadow, cast by the earth in space (Fig. 13). As in the case of eclipses of the sun, this does not occur every month, and for the same reason as already explained, and illustrated in Fig. 13 of Chapter I. If the moon revolved around the earth in the same plane as that in which the earth revolves around the sun, there would be a solar and a lunar eclipse every month. As it is, the moon's orbit does not lie in this plane, being inclined to it at an angle of just over 5° , and there are comparatively few eclipses, the number varying each year. Even under the most favorable conditions

there can never be more than seven eclipses in any one year—some times there are as few as two—and of these the numbers of solar and lunar eclipses are not necessarily equal.

An eclipse of the moon is different in character from an eclipse of the sun, for the obscuration of the moon in the earth's shadow is not a local but a general phenomenon. We have already seen that a total eclipse of the sun is seen only from those places over which the line of totality passes, and that on either side of this restricted area the occurrence is seen as a partial eclipse. On the other hand, an eclipse of the moon is visible to the same extent to people in all those parts of the earth from which the moon is visible at the time. To express it in another way, a solar eclipse is due to the moon's shadow passing

over certain places on the earth, while a lunar eclipse takes place in space, the shadow of the earth being seen on the actual surface of the moon. Eclipses of the moon may be partial or total, the former occurring when the moon does not completely enter the earth's shadow. For the reasons already explained, a partial lunar eclipse is visible to everyone as a partial eclipse and a total eclipse as a total eclipse, whereas a total eclipse of the sun may be seen as a total eclipse from some places and as a partial eclipse from others.

The shadow cast by the earth extends into space as a great cone and reaches far beyond the orbit of the moon. Consequently, the moon is plunged into this shadow for a length of time that varies according to the distance of the moon from the earth



Fig. 13. As the moon circles round, it sometimes passes through the earth's shadow and is eclipsed. Its distance from the earth at these times determines the length of the eclipse. The moon's orbit is elliptical with the earth at one of the foci. Consequently the moon is nearer the earth at some times than at others. Thus at A, the eclipse is longer than at B, for at A the moon passes through a wider shadow

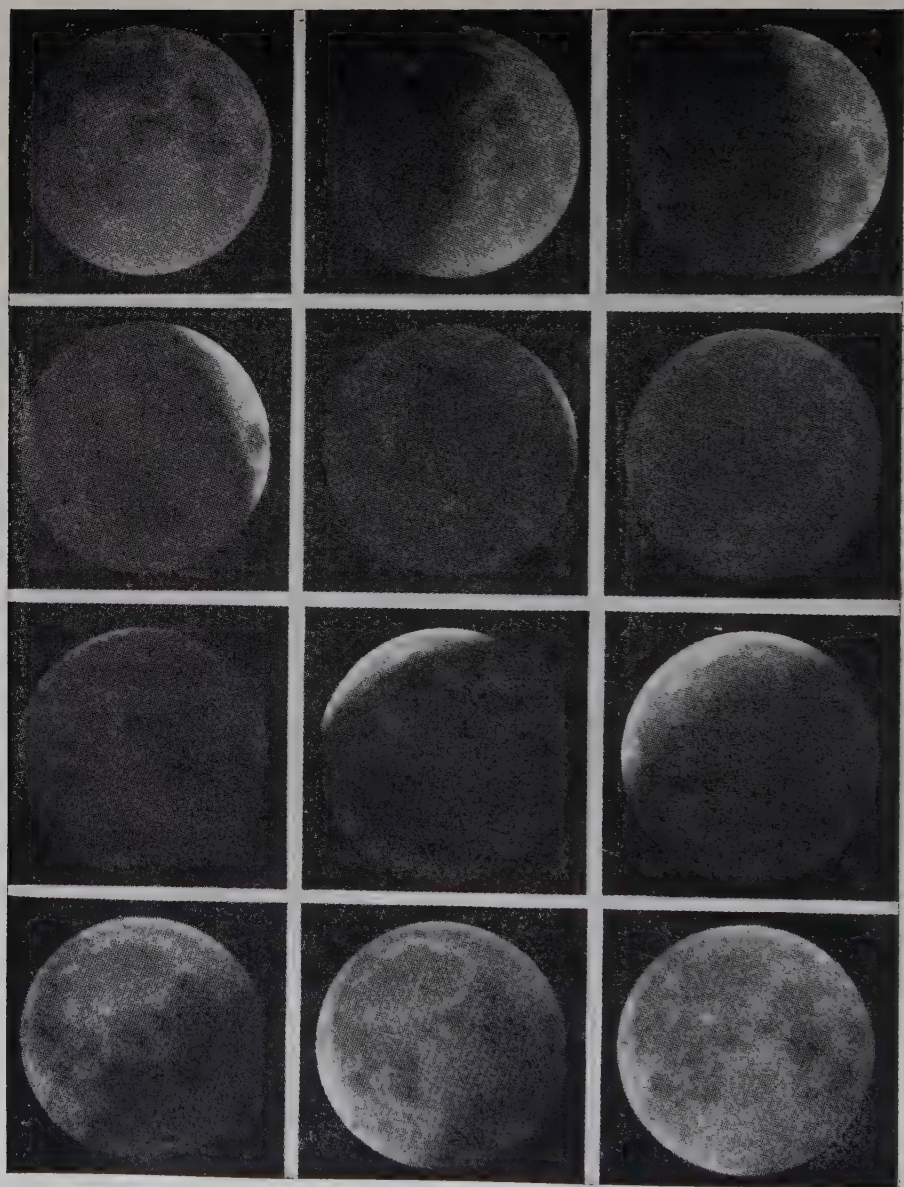


Fig. 14. A total eclipse of the moon photographed at its various stages. The right hand photograph in Row II was taken at full eclipse, the moon being still visible

at the time of the eclipse. The greater the distance, the less the diameter of the shadow through which the moon must pass; and consequently the

shorter the duration of the eclipse. (Fig. 13.) The moon may remain eclipsed for as long as 1 hr. 50 min. if conditions are favorable.

THE "GHOST" MOON

At these times, although technically said to be "completely obscured," the moon may usually be seen as a ghost of its normal self, sometimes copper-colored, or sometimes brown or gray. This variation in the coloring is due to refraction by the earth's atmosphere of the sunlight that falls on it from the opposite side. When the eclipse takes place, the moon is on the dark side of the earth, the light from the sun falling on the opposite hemisphere. Some of this sunlight striking the edges of the earth is refracted inwards by the atmosphere, the rays being thus caused to fall on the surface of the moon, partially illuminating it. That the moon, although totally eclipsed, may yet be visible is illustrated in Fig. 14 by the third photograph in the second row. As we shall learn in a later section, the amount of water vapor in our atmosphere varies from day to day,

and we can understand, therefore, that the degree of refraction varies similarly, so causing a difference in color of the eclipsed moon as between one eclipse and another.

EARLIEST RECORDED ECLIPSE

The earliest record of a lunar eclipse is found in a Chinese book, discovered in A.D. 280 in the tomb of an emperor who had lived many centuries previously. The eclipse here referred to is probably that of January 29, 1136 B.C.

The last total eclipses of the sun to be seen from this country were in 1925 and 1932. The next two total eclipses of the sun visible in North America will occur on July 9, 1945 and June 30, 1954, both of these visible from Canada. The next one actually visible from the United States proper will occur on March 7, 1970, and will be visible from the state of Florida.



Fig. 1. An artist's impression of what the markings on Mars might look like. It is quite unproved that they are in fact canals made by human or near human beings

CHAPTER 3

THE PLANETS

UNTIL the middle of the sixteenth century the earth occupied a more important position in the mind of man than it has occupied since that time. Never again will it achieve the same degree of importance. Up to that time it was believed that the earth was the center of the universe and that the sun and all the heavenly bodies revolved around it. Today every schoolboy knows that far from being the center of the universe, as Ptolemy taught, the earth is not even the center of that particular part of the universe to which it belongs. It is merely a planet that circles around the sun in company with eight other planets, some of which are enormously larger than the earth. De-throned from its proud position, it is seen in its true light—a speck of solidified gas—a nonentity in the vast cosmos, and apparently of about as much importance in the celestial scheme as a single grain of sand on the Sahara Desert.

THE SOLAR SYSTEM

The earth and its fellow planets, with their satellites, together with a number of minor bodies, the asteroids, the comets, and the meteors, form the solar system (Fig. 2). The planets have no light of their own and shine only by reflecting the light of the sun, exactly as does the moon. Each planet moves around the sun in a regular, mathematically calculable path or orbit. Those nearest to the sun complete a circuit in a comparatively short time; those further away take longer.

Fig. 3 illustrates approximately the

comparative size of the planets, as compared with the sun, the size of which in the diagram is represented by the equatorial section below the

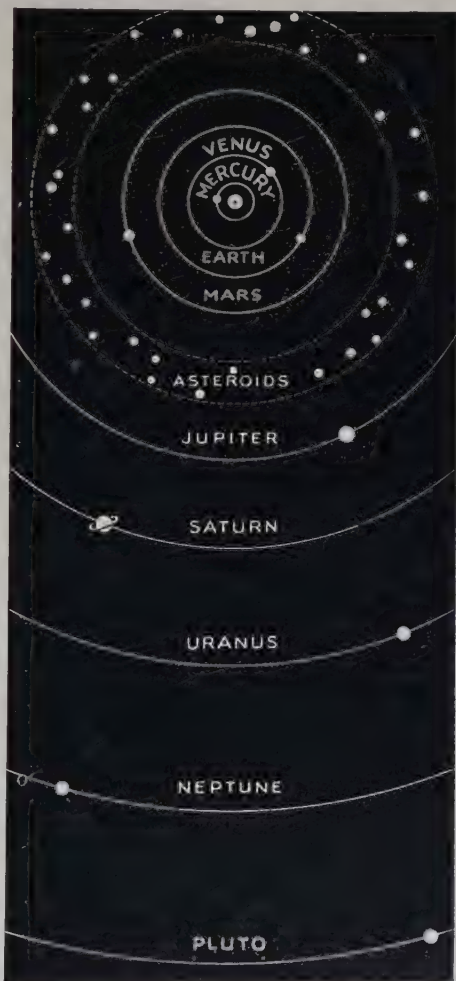


Fig. 2. The Solar System. Because of space limitations neither the planets nor their orbits in the heavens have been drawn to scale

planets. We are better able to visualize the relative sizes and distances separating the sun and the earth if we imagine a model in which the sun is represented by a 9-ft. globe. On the same scale the earth would be represented by a ball 1 in. in diameter at a distance of nearly 1,000 ft. Between the orbit of the earth and the sun are the orbits of two other planets, Mercury and Venus. They would be respectively represented in our model by a large pea 380 ft. distant and a 1-in. ball at a distance of 700 ft. from the 9-ft. globe representing the sun.

and even earlier allusions to it were made by the astronomers of Nineveh in a report they made to Assurbanipal, King of Assyria.

Mercury is believed to rotate on its axis in the same period of time as it revolves around the sun, namely 88 days. Thus, it always presents one face to the sun, so that one side of the planet is in perpetual light and the other in perpetual darkness. On that side facing the sun, the temperature must be about 350°C .—or more than enough to melt lead—while on the other side it must be extremely cold,

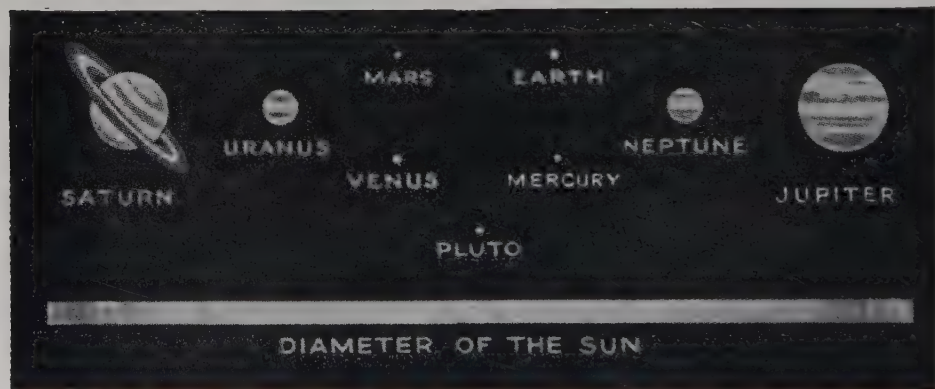


Fig. 3. The comparative sizes of the nine planets of the solar system

Mercury, the planet nearest to the sun, is the smallest planet and completes one revolution of its orbit in about 88 of our days. We do not often see Mercury, for as it is never at a greater angle than 28° from the sun (in relation to the earth), it is generally overpowered by the brightness of the sunlight. The best times to see it are in the evenings in spring and in the early mornings in the autumn. Despite this difficulty of observation, Mercury was well known to the ancients. It was called "the Sparkling One" by the Greeks; Chinese astronomers observed it as early as A.D. 118;

because there is no atmosphere to circulate heat from the illuminated side. There can be no life on Mercury—as Professor Lowell has said, the planet is merely "the bleached bones of a world."

WHY VENUS IS SO BRIGHT

Between the orbits of Mercury and the earth lies that of the planet Venus, which revolves around the sun in about 225 of our days. Unlike Mercury, Venus is easily seen and often is so bright that general attention is called to it, letters to the papers frequently asking about "the extraor-

dinarily bright star seen in the sky last night." The particular brightness of Venus is caused by the fact that the planet itself, which is about the same size as the earth, is surrounded by a dense atmosphere that reflects a large proportion of sunlight. This cloud envelope makes it difficult for us to see anything beneath, however, and beyond a few dusky markings nothing is known of the planet's surface, but it is believed by scientists who have made a special study of this planet that it probably rotates on its axis somewhere in the neighborhood of thirty days.

Because the planets Mercury and Venus lie between the earth and the sun it naturally follows that in the telescope these planets will exhibit many different phases, just as the moon does. Thus we may have a "new" or "half" Mercury, a gibbous or a crescent Venus, depending entirely on the relative positions of the sun, the earth, and these two planets.

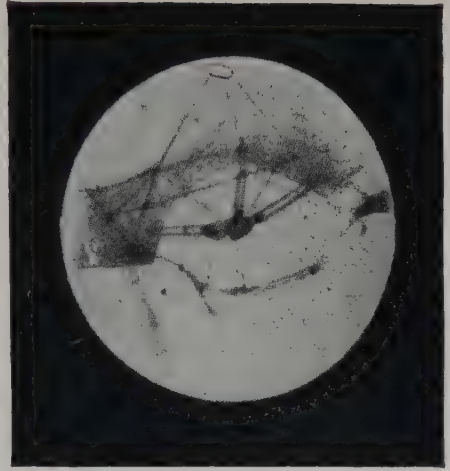


Fig. 4. Mars as drawn by Professor Lowell. At the top is the South polar cap and the surface of the planet shows distinctly, several "canals"

MARS AND ITS MYSTERIES

Beyond the orbit of the earth is that of Mars, best known of the planets, because of the so-called canals that

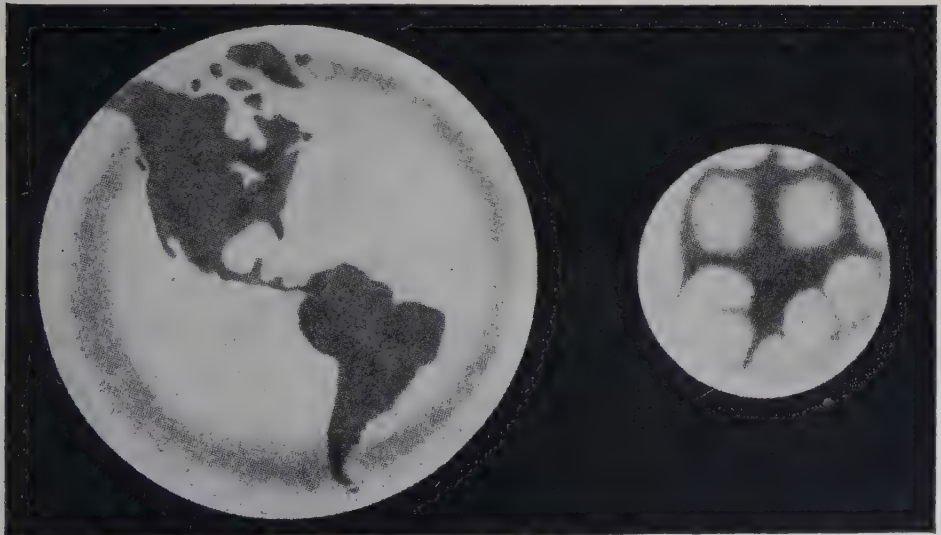


Fig. 5. The comparative sizes of the earth (diameter 8,000 miles), and of Mars (diameter 4,215 miles)

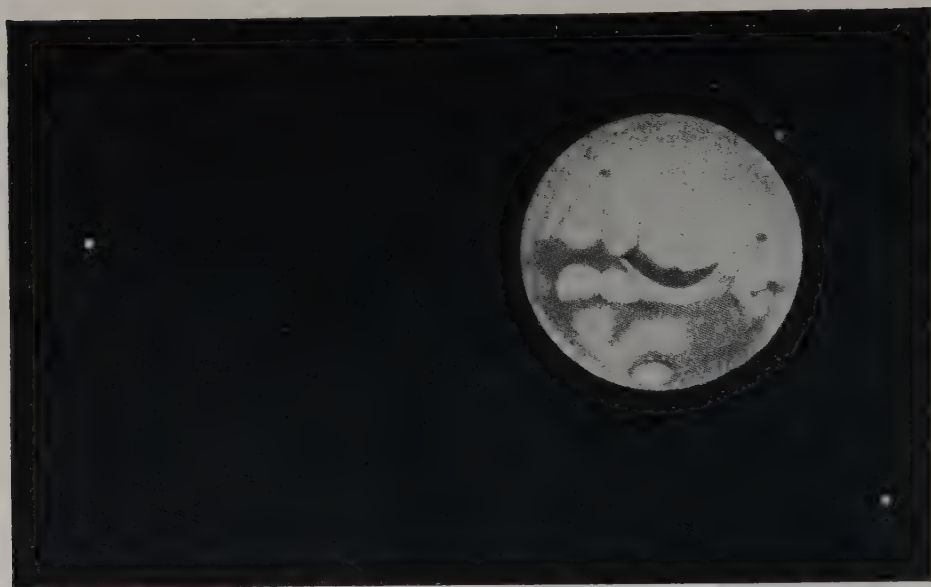


Fig. 6. Mars and its tiny satellites, Deimos and Phobos. Note the polar cap and the "canals"

have been seen on its surface and the suggestion that the planet may be inhabited by intelligent creatures. As the diameter of Mars is 4,215 miles, it is a little over half the diameter of the earth (Fig. 5). In our model it would be represented by a marble ($\frac{1}{2}$ in.) at a distance of 495 yards from the 9-ft. sun. Actually its distance from the sun is about 141,000,000 miles, and it completes a revolution in its orbit in 687 of our days. Thus the "year" on Mars is nearly twice that on the earth.

Unlike Venus, very few clouds obscure the Martian surface. The telescope shows dusky markings that persist year after year, suggesting that they are permanent features of the Martian landscape (Fig. 4). We can see that the surface of the planet is practically level, mountains being unknown, and that at the poles are white patches that increase and diminish

with the Martian seasons. These are the Martian polar caps, probably composed of ice and snow and analogous to our own Arctic and Antarctic regions. They have been carefully observed over many years. Sometimes great chasms have been noticed in the South polar cap, portions of which have become detached at the breaking up of the ice and snow with the advance of the Martian summer.

The deposits of ice and snow in the polar regions are less than those on the earth, and sometimes they disappear entirely. During the summer the dark markings are generally of a greenish color, presumably due to vegetation, since they change to russet-brown with the approach of autumn. The remainder of the surface is the orange-yellow of a desert, looking as we would expect the Sahara or the great Arabian Desert to appear if seen from a similar distance.

Undoubtedly Mars has an atmosphere, though it is at best a rarefied one, and the spectroscope has shown that it contains the aqueous vapor that—as we shall see in a later section—is so necessary to life. The climate would appear to be much colder than that of the earth. The temperature has been measured, however, and has been found to be high enough to support some forms of life that we know on the earth. The surface of the planet has been closely studied over many years by many observers. Maps have been made, together with thousands of drawings and hundreds of photographs, showing the planet under all conditions year by year.

THE CANALS OF MARS

In 1877, G. V. Schiaparelli, Director of the Milan Observatory, found that many of the dark markings on Mars are joined together by a network of fine lines. It is these mysterious markings—the “canals”—that have caused so much discussion (Fig. 4). The canals appear always to run in straight lines, taking the shortest route from point to point. They maintain a uniform breadth of about ten to twenty miles, and vary in length from a few

hundred to 3,000 or 4,000 miles. The late Dr. Percival Lowell, who founded the observatory, named for him, at Flagstaff, Arizona, specially to study Mars, believed that the canals are of artificial origin and that they have been made by the inhabitants of our neighboring planet to lead water from the melting polar caps through the Martian deserts in a gigantic irrigation enterprise.

The reason for the prodigious enterprise of this complicated canal system (if such it is) is found in the fact that as there are no mountains and very few clouds on Mars there can be very little rain, and consequently no rivers. If the planet is inhabited, the Martians must grow vegetable food for their subsistence. In view of the permanent water famine, water must be brought from the melting polar caps to irrigate the Martian deserts with the semi-annual unlocking of the polar snows. What we see are not the actual canals but the vegetation that grows in the desert area through which they run. Could we look back at the earth from Mars we should see very much the same thing taking place after the yearly inundation in the Nile Valley.

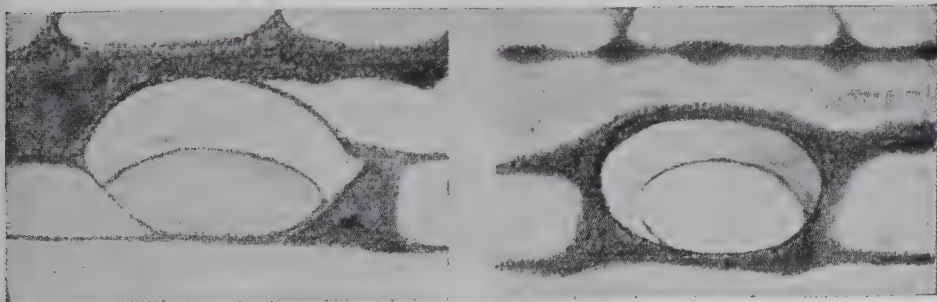


Fig. 7. Two views of the mysterious Red Spot of Jupiter showing the well known “Hollow.” In the left drawing, the almond shaped Red Spot is more prominent; in the right, the “Hollow” is more noticeable. These markings are not yet fully understood

It is only fair to say that there are others who do not support this interesting theory. They think all those observers who have seen and drawn the canals are suffering either from an optical illusion or a vivid imagination. There is no question, however, that some strange markings do exist—the argument is as to their actual nature and significance. One obstacle that has to be overcome by those who disbelieve the canal theory is the fact that the canals are undoubtedly connected with the Martian seasons. They disappear in the winter and reappear in spring and summer, behaving, indeed, exactly as they would if their appearance was due to the growth of vegetation brought to life by the water that is released from the polar caps in spring and summer.

As a result of his work, Percival Lowell was convinced that Mars is inhabited by beings of some kind or other, but it is uncertain in exactly what form these beings may exist. The theory of the existence of intelligent life on Mars, Lowell said, may be likened to the atomic theory in chemistry, in that in both we are led to believe in units that we are unable to define. Both theories explain the facts in their respective fields and they are the only theories that do, but we can no more say what an atom may resemble than we can be certain what a Martian may be like. The behavior of the chemical compounds points to the existence of atoms too small for us to see, and in the same way, the aspect and behavior of the Martian markings implies the action of agents too far away to be seen.

This is much farther than most astronomers would be willing to go. At the present time the consensus of opinion among astronomers seems to

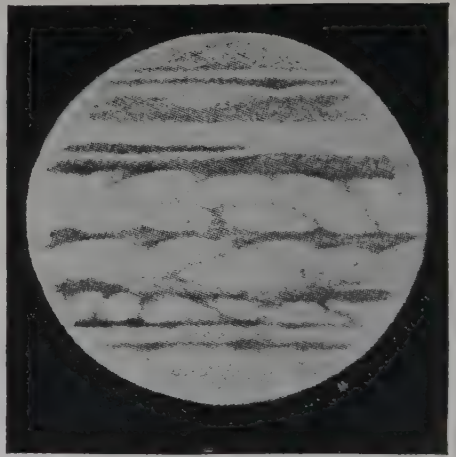


Fig. 8. Jupiter showing characteristic cloud belts lying parallel to its equator. Note its distinctly oval outline combined with the marked flattening at the poles

be that there is very probably some sort of life on Mars—at least plant life—but that to draw larger conclusions than this can be no more than sheer conjecture.

THE SATELLITES OF MARS

Mars has two tiny satellites, named Deimos and Phobos, discovered in 1877 by Professor Asaph Hall at the United States Naval Observatory (Fig. 6). The outer satellite, Deimos, is estimated to be 5 miles in diameter, and Phobos, the inner one, 10 miles in diameter. They afford some idea of the excellence of modern telescopes, for their size and distance when observed from the earth is comparable to that of two apples hung over the city of Cleveland and observed from Pittsburgh.

Phobos revolves around Mars in 7 hr. 39 min., which is less than one-third of a Martian day. (This is the only satellite in the solar system that revolves around its primary planet in less than one day of the planet).

JUPITER

Jupiter is the largest planet of the solar system, and sufficiently large to contain more than 1,000 planets the size of the earth. It is nearly 88,000 miles in diameter and is about 483,000,000 miles from the sun, requiring nearly 12 years to complete one revolution. Taking our earlier illustration, Jupiter on the same scale would be represented by an 11-in. globe situated approximately a mile distant from the 9-ft. globe which represents the sun.

As seen in the telescope, Jupiter is distinctly flattened at the poles (Fig. 8). Actually this flattening, which amounts to about $\frac{1}{16}$ of the whole, was produced, while the planet was not yet completely solidified, by the very rapid rotation on its axis—the period of rotation being less than ten hours. The planet's surface is crossed by alternate light and dark belts, which on close inspection are seen to be composed of clouds (Fig. 8). Although constantly altering in appear-

ance, they always lie in well-defined parallel zones, which for purposes of identification are named after the corresponding zones on the earth.

One of the recent discoveries of astronomy is the spectroscopic evidence of ammonia and methane in the atmosphere of Jupiter. Terrestrially methane is a constituent of natural gas and is the poisonous "fire-damp" which causes so many fatalities among regularly employed miners.

Although, as a rule, the details of the cloud belts are constantly changing, there is in the South Equatorial Belt a peculiar spoonlike marking, called the Great Red Spot, that seems to be of a more permanent nature (Fig. 7). It was quite conspicuous in 1878, and since that date it has been the object of close study by many observers. This mysterious feature, which measures some 30,000 miles in length and 7,000 miles in breadth, has been described as varying from a full brick-red color to rose-pink. It is situated in a kind of bay called the "Hol-

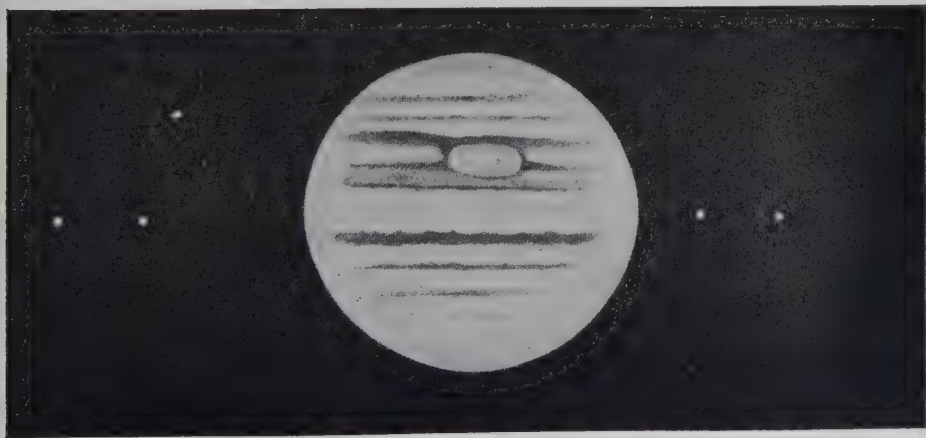


Fig. 9. Jupiter with four of its principal satellites. Besides these four moons, which were discovered by Galileo, Jupiter has seven other satellites. The Red Spot and Hollow can also be seen

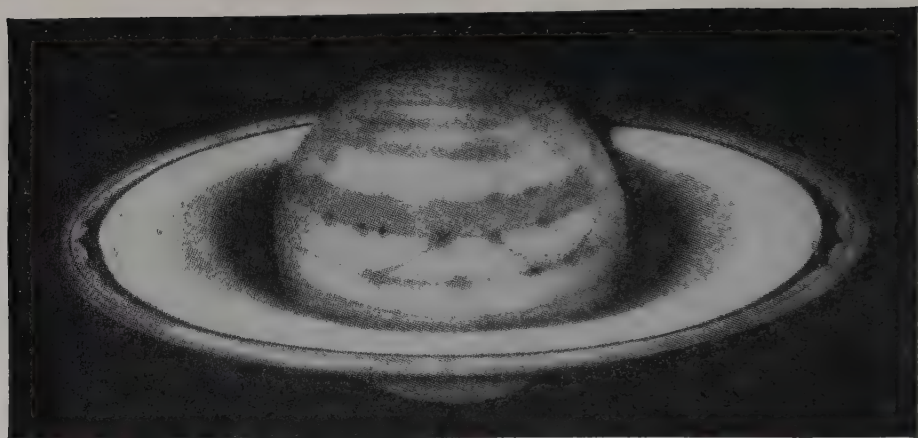


Fig. 10. An artist's drawing of the beautiful planet, Saturn, shown surrounded by its unique ring system

low," which is so clearly defined as to be visible even in a small telescope. The Red Spot was rather prominent in 1918-19 and again in 1936, and on both these occasions the Hollow became correspondingly faint. No satisfactory explanation has yet been put forward to account for this peculiar feature. In the early days it was thought that it might be the mouth of some huge volcano, rearing its head above the clouds that lie above the surface of the planet. This was later shown to be impossible, however, for it was found that the Red Spot has a proper motion of its own—that is to say, it moves on its own account as well as partaking in the general axial rotation of the planet. Whereas the average time for the rotation of the Equatorial Zone is 9 hr. 50 m. 30 sec., and for the Temperate Zone 9 hr. 55 min. 40 sec., the rotation period for the Red Spot is 9 hr. 55 min. 37 sec. A possible explanation of this mysterious object is that it is a new satellite in the process of formation—some great continent, perhaps, torn off from the surface of the planet, pre-

cisely, indeed, as is believed by some astronomers to have occurred in the origin of our own satellite, the moon.

JUPITER'S ELEVEN SATELLITES

Jupiter is already rich in satellites, having no less than eleven. The four principal ones (Fig. 9) were discovered by Galileo and used by him as an illustration to support the Copernican theory that the earth revolves around the sun. These four satellites—the largest of which, Ganymede, is 3,550 miles in diameter—present a succession of interesting phenomena. As they pass behind the planet they are "occulted," that is, concealed. Again, when they pass into the great shadow cast by Jupiter in space, they are eclipsed exactly as our moon is eclipsed when it passes into the earth's shadow.

The tenth and eleventh satellites of Jupiter were discovered in 1938 by Dr. Seth B. Nicholson of the Mount Wilson Observatory, using the 100-inch telescope. Dr. Nicholson in 1914 had also discovered the ninth satellite of Jupiter.

It is rather remarkable to find that the three outermost satellites revolve round Jupiter in a retrograde direction—that is to say in a direction contrary to that generally followed by their fellow-satellites and by nearly all of the satellites of the other planets. For this and other reasons it has been suggested that these bodies are not genuine satellites but minor planets that have approached too close to Jupiter and been drawn into its system by the effects of gravitation.

Saturn, the planet beyond Jupiter, is regarded by many as being the most beautiful object that can be seen through the telescope, because of the vast system of "rings" that encircles it (Fig. 10). Its size, in comparison with a 9-ft. globe representing the sun, is that of a 9-in. globe at a distance of $1\frac{1}{4}$ miles. Actually its diameter is 73,000 miles, its distance from the sun being 886,000,000 miles.

Galileo was puzzled by the appearance of the planet as seen in his small and imperfect telescope. When he first observed it, the planet appeared to him as though accompanied by two smaller "stars" on opposite sides. Later, he was surprised to find that the two smaller "stars" had disappeared and that Saturn was but a single globe. Very perturbed at this, and thinking he had made a mistake in his previous observation, he wrote: "Are the two lesser stars consumed after the manner of the solar spots? Have they vanished or suddenly fled? Has Saturn, perhaps, devoured his own children? Or were the appearances indeed illusion and fraud? I do not know what to say in a case so surprising, so unlooked for, and so novel. The shortness of the time, the unexpected nature of the event, the

weakness of my understanding, and the fear of being mistaken, have greatly confounded me."

It was not until some years later that the explanation of these curious changes was discovered, when Huygens came to the conclusion that Saturn was surrounded by a flat ring-system. This, he concluded, is inclined to the ecliptic—the great circle on the celestial sphere along which the sun apparently travels during the year—and nowhere touches the body of the planet. The rings vary in their aspect because of the alteration of the angle at which they are tilted towards the earth (Figs. 11 and 12). Thus, it is that we sometimes see a broad expanse of ring that gradually decreases



Fig. 11. Three views of Saturn's rings. At top, the rings seen edgewise are almost invisible

as the angle becomes less acute. Ultimately a point is reached when the rings are edgeways to us, and at this time they are practically invisible, as shown in the top illustration of Fig. 11. They run through this cycle of changes in 30 years. Galileo's telescope was not powerful enough to distinguish the ring in any essential details, as already explained. What he thought were two stars were the portions of the ring seen on either side of the globe of the planet itself.

WHAT ARE SATURN'S RINGS

Actually, the rings are not solid but are made up of a multitude of tiny bodies each revolving in its own orbit around the planet so that they may

be regarded as a huge number of tiny satellites. Two rifts, or blank spaces, called "divisions," may be seen in the rings where there is an absence of satellites, so that the number of concentric rings is three, the outermost, the middle, and the innermost. The diameter of the ring system is about 171,000 miles—about twice the diameter of the globe of Saturn—and they are about 10 miles thick. The innermost ring is less dense than the outer rings and for this reason is known as the Crepe Ring.

In addition to this wonderful ring system, Saturn has nine satellites, the largest of which—Titan—is equal in size to the planet Mercury. Phoebe, the faint and distant satellite, which

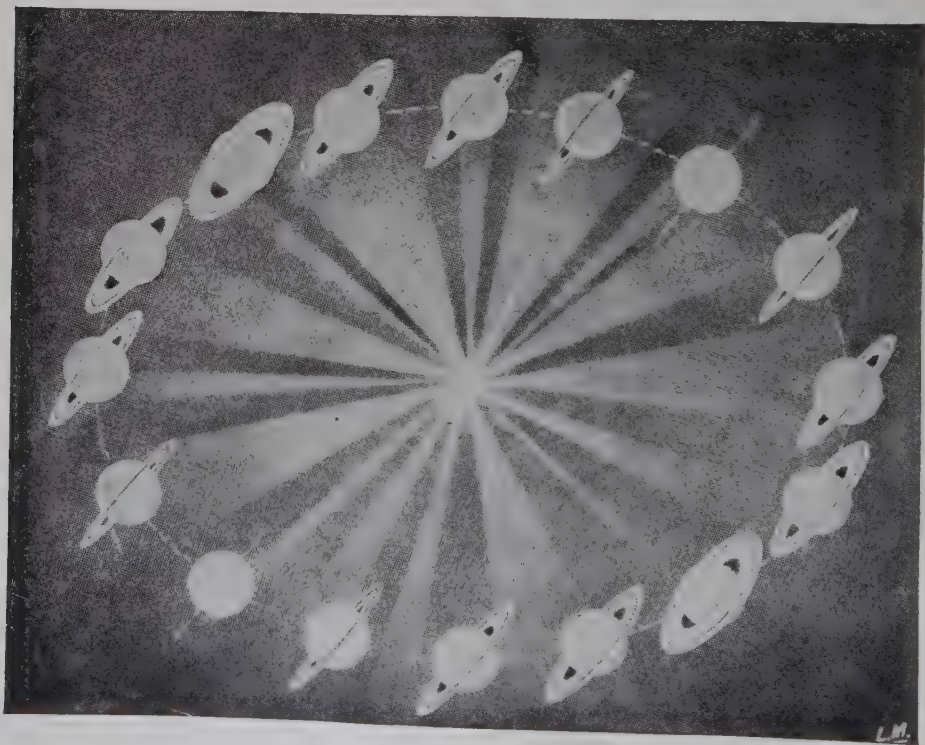


Fig. 12. Phases of Saturn's wonderful ring system as it moves on its journey round the sun

was discovered in 1898 by Wm. H. Pickering has a retrograde motion, as have the three outermost satellites of Jupiter. In 1905, Pickering reported the discovery of a tenth satellite of Saturn, which he named Themis, but this discovery has not been confirmed.

The globe of Saturn is marked by cloud belts somewhat similar to those of Jupiter, and they also lie in zones parallel to the planet's equator. Similarly, the globe is slightly oval, bulging at the equator. This is probably due to the physical condition of the planet and to the fact that it revolves on its axis in the comparatively short period of 10 hr. 15 min.

By means of the spectroscope, ammonia and methane have been discovered in the atmosphere of Saturn as well as Jupiter.

Of the physical characteristics of the three planets beyond Saturn we do not know much, owing to their comparatively small size and their immense distances. There are interesting stories concerning the discovery of each of them, however, and these we shall briefly detail in the next few pages.

DISCOVERY OF URANUS

Uranus was discovered in 1781 by William Herschel (1738-1822), who deserted from the Hanoverian Guards to become an organist at Bath. He was a born musician and while studying the theory of music was led to interest himself in mathematics. From this subject to optics and astronomy was but a step, yet it changed the whole current of his life. Astronomy fascinated him and his music became a very secondary consideration—merely a means to an end. All his spare time was spent in constructing telescopes, each one larger and better

than the one before. He hurried home from conducting concerts at Bath, and set to work without troubling even to remove his cravat and ruffles. He transformed his house into a laboratory; his drawing room became a carpenter's shop; and he had lathes even in his bedroom.

As a result of these labors he constructed the largest telescope the world had seen up to that time. He set it up in his back garden and commenced a survey of the heavens, at which task he continued to work for seven years. In 1781 he commenced a systematic examination of all stars over a certain magnitude, and on March 13th he made his great discovery that added a sixth planet to the known solar system.

As seen through any telescope, the stars appear as sparkling points of light of varying magnitude, but the planets appear as discs. Busily examining the stars in accordance with his plan, Herschel passed them in review one by one, noting their differences in magnitude and color. One of the objects that came into view attracted his special attention, for its appearance was different from that of the objects he had been examining for so many years. It was not a point of light but a tiny disc, and Herschel quickly realized this could be no star. This was confirmed when he noted that, unlike the stars, it had a movement of its own.

Although it seemed that this strange object must be a planet, Herschel did not dare to suggest this, for the five planets—all visible to the naked eye—had been known from ancient times and the solar system long had been regarded as complete. He tentatively suggested that it might be a comet, but subsequent measurements of its

movements left no doubt that the object was actually a new planet. The astonishment of the scientific world was unbounded, but it scarcely surpassed the admiration that was aroused for the industry of the Bath musician. Herschel was commanded to appear before George III, who was so impressed by his work that he appointed him his astronomer at Windsor, and in this capacity Herschel continued his observations for many years.

VALUE OF CAREFUL RESEARCH

The discovery of Uranus is an excellent illustration of the value of careful and systematic effort, for it was subsequently found that the object had actually been deliberately and carefully measured on no less than seventeen occasions by different astronomers before the memorable night when it was first examined by Herschel. Any one of these observers, exercising greater care or having greater experience, might have claimed the honor of discovering a new planet.

Uranus is about 31,000 miles in diameter, and is some 1,782,800,000 miles distant from the sun. On the scale of our model, with the sun a 9-ft. globe, it would be represented by a 4-in. globe at a distance of $3\frac{1}{2}$ miles. It has four satellites, two of which were discovered by Herschel.

HOW NEPTUNE WAS FOUND

Astonishing though the discovery of Uranus was, the finding of Neptune—the planet beyond Uranus—was even more amazing, for it was actually discovered on paper before it was seen in the telescope! This marvelous “triumph of mind over matter” came about in this way.

After its discovery, Uranus was carefully observed and its position noted year by year. Tables were produced giving its exact future positions for several years ahead. This is customary with all the planets, the results appearing in the annual known as the *Nautical Almanac*. As time went on it was found that evidently there was some error in the tables, for it was noted that Uranus was not “running to time” and was not in the positions indicated by the tables. The calculations were checked over and more accurate tables were published, but again unaccountable discrepancies were apparent between the predicted positions and the planet’s actual positions. At length it was suggested that the only adequate explanation was that there must be yet another planet circling around the sun beyond the orbit of Uranus; and that this other planet, by its gravitational powers, sometimes retarded Uranus so as to make it move more slowly and be late, and at other times accelerated its movement so that it was early.

To search among the tens of thousands of stars for such a body was impossible in those days when celestial photography was unknown. More particularly was this so in this case as the immense distance of the suspected planet would make it far more difficult of observation than Uranus, even assuming its size was the same—a fact that was not established. The alternative was to calculate the position of the suspected planet using the observed discrepancies in the movement of Uranus. Although this was a mathematical problem of surpassing difficulty, it was undertaken by U. J. Leverrier, a French mathematical astronomer, and by J. C. Adams, a student at Cambridge, England. In 1841,

Adams had interested himself in the subject and had made a note in his diary to "investigate the irregularities of the motions of Uranus, which are as yet unaccounted for, in order to find whether they may be attributed to the action of an undiscovered planet beyond it; and if possible, thence to determine the elements of the orbit approximately, which would lead to its discovery."

INDEPENDENT DISCOVERIES

The two mathematicians worked independently on the problem, neither knowing that the other was at work. In October 1845 Adams left at Greenwich Observatory the results of his work, showing the hypothetical elements and position of the supposed planet. Instead of making a search, however, the Astronomer Royal paid no attention to the documents handed to him by the young Cambridge graduate, placing them in a drawer from which they were not brought to light until later.

Meantime, in France Leverrier completed his results, and when a copy of these reached the Astronomer Royal, on June 23, 1846, he remembered the papers that Adams had left with him nine months before. Turning them up he was struck by the similarity in the results obtained independently by the two mathematicians. He at once wrote to Professor Challis, who was in charge of the 25-in. telescope at Cambridge, asking him to look in the position indicated for the supposed planet. Before Challis could set to work, however, it was necessary to make a map of the stars in the locality to be examined, and so some appreciable period of time had to elapse before the search could be commenced.

Leverrier had also sent his results to Galle, of the Berlin Observatory, where the observers were more fortunate, for it so happened they had recently obtained some star maps, copies of which had not at that time reached Cambridge. The search could be, and was, commenced immediately and a few hours later (on September 23) a strange object was found almost at the exact spot indicated by Leverrier. A week later Challis, at Cambridge, found the same object from Adams's figures, and it was soon shown that this was a new planet. Thus one of the mysteries of astronomy was dramatically solved.

Little is known of Neptune: it is situated some 2,793,500,000 miles from the sun—a distance so great that it is a difficult object to see except with a fairly large telescope. On the scale of our model it would be represented by a 5-in. globe, $5\frac{1}{2}$ miles distant from the 9-ft. globe representing the sun. Neptune requires nearly 165 years to complete one revolution in its orbit around the sun. Its only satellite is too small actually to be measured but it has been calculated that it must be over 2,000 miles in diameter to enable it to be seen from such a great distance.

Towards the end of the last century, when history repeated itself and perturbations (irregularities) were noticed in the motion of Neptune, there naturally arose the question whether it could be regarded as being the outermost planet in the solar system. The possibility of the mathematicians repeating their achievements with Uranus and Neptune was considered to be practically ruled out, because in this case the quantities that might be used as a basis were so minute.



Fig. 13. Pluto, as photographed at intervals of several nights at the Lowell Observatory in 1930, the year of its discovery. The object indicated by the arrows was seen to have moved a considerable distance and so proved to be a planet and not a star

Dr. Percival Lowell, whose original work on Mars we have already mentioned, interested himself in the possibility of the existence of the trans-Neptunian planet. He attacked the problem from the point of view of the perturbations that such a planet would have on the movements of Uranus, because Neptune has not even yet been observed over a suffi-

ciently large part of its orbit to enable sufficiently accurate observations to be made. The method he adopted was to account for the various effects of Neptune and the other planets on Uranus, so that should there be any residue unaccounted for, after all known effects were deducted, such residue could only be due to some planet beyond Neptune. Admittedly the amount of this residue would be small—Lowell stated that the value could not exceed 4.5 seconds of arc as compared with the 133 seconds that Adams and Leverrier worked on in 1845.

THE NINTH PLANET

Notwithstanding these great difficulties, Dr. Lowell discovered sufficient evidence to warrant a belief that there was a planet beyond Neptune, and that it moved in an orbit with a radius of about 45 times that of the earth. Early in 1930 a long search—carried out appropriately at the Lowell Observatory—resulted in the discovery of a trans-Neptunian planet (Fig. 13). Beyond the fact that this ninth planet, named Pluto, is about equal in size and mass to Mars, we know but little about it as yet. Pluto's distance from the sun is nearly forty

times greater than that of the earth, that is, nearly 4,000,000,000 miles. Its period of revolution around the sun is about 248 years. Its orbit is the most eccentric of all the nine major planets and is inclined to the plane of the earth's orbit by a greater amount than any of the others—a fact attested by careful mathematical calculations.

Pluto was discovered by Clyde W. Tombaugh, an assistant astronomer at the Lowell Observatory, in a program of search for a trans-Neptunian planet initiated by Dr. Percival Lowell, founder of the observatory, and carried on by Dr. V. M. Slipher, the present director. The new planet was found by photography through a 13-inch astrographic telescope presented to the observatory by Dr. A. Lawrence Lowell, a brother of the founder, and formerly president of Harvard University.

Having now reached the boundaries of the solar system, we must call a halt, and return for a moment to the space between the orbits of Mars and Jupiter. This space is occupied by the minor planets, or asteroids (Fig. 14), the existence of which was unsuspected until the end of the eighteenth century. Their discovery came about in an extraordinarily interesting manner.

BODE'S LAW

In the year 1772, a German astronomer, J. E. Bode (1747–1826), drew attention to a curious relationship between certain figures and the distances of the planets from the sun. (This relationship was first noticed by Titius of Wittenberg some twenty years earlier.) If numbers be written down of which each (except the first and the second) is double that of the preceding number (thus: 0, 3, 6, 12,

24, 48, 96, 192, 384) and if 4 be added to each number, the following sequence is obtained: 4, 7, 10, 16, 28, 52, 100, 196, 388.

These figures, divided by ten, give fairly accurately the mean distances of the planets from the sun in astronomical units. (An astronomical unit is the mean distance of the earth from the sun, that is, about 93,000,000 miles.) This is clearly shown in the following table:

Planet	Distance in astronomical units	Distance as shown by Bode's Law
Mercury ..	0.39	.4
Venus ..	0.72	.7
Earth ..	1.00	1.0
Mars ..	1.52	1.6
Asteroids ..	2.65	2.8
Jupiter ..	5.20	5.2
Saturn ..	9.54	10.0
Uranus ..	19.19	19.6
Neptune ..	30.07	38.8
Pluto ..	39.52*	77.2

* This figure is only approximate as yet, and further observations must be made before it can be confirmed.

The above table (shown in relation to Bode's Law), has been compiled in the light of modern discoveries; but when the Law first attracted attention only the six planets of the ancients were known. When Uranus was discovered in 1781 it was found that its orbit fitted in with the figure 19.6. With the two outermost planets, Neptune and Pluto, the Law breaks down rather badly, but we are not at the moment concerned with that aspect of the matter.

We are concerned, however, with the fact that in Bode's day—and indeed today—there was no major planet

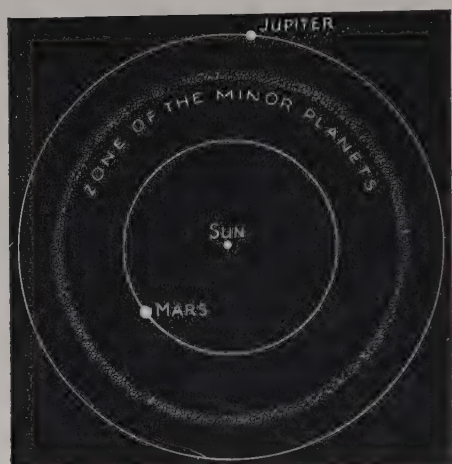


Fig. 14. Where the orbits of the asteroids or minor planets lie

which corresponded with the figure 2.8. It was therefore imagined that there existed an empty zone between the orbits of Mars and Jupiter. Another German astronomer, Kepler, had predicted that some very small planet might be found in this zone, and in 1800, Baron von Zach and several other astronomers met at Lilienthal and decided to make a systematic search for such a planet. These "celestial police," as they called themselves, divided part of the sky into 24 divisions, one being allotted to each observer, who was to examine the stars in his zone every night in the endeavor to see if there was any strange body among them.

Before these enthusiasts could get to work, Piazzi, the Director of the Palermo Observatory in Sicily—who was compiling a catalogue of stars—charted the position of what he regarded as a star of the eighth magnitude. Observing this same object on successive nights, he found that it had a motion of its own such as no real star has, and—as Herschel had done with Uranus—he came to the conclusion that he had discovered a comet. He soon realized, however, that what he had seen was really a new planet, although only a small one. In due course it was found that the orbit of this new planet fell between those of Mars and Jupiter, and as it therefore filled the blank space in Bode's table the solar system was regarded as complete. The new planet, which was named Ceres, after the patron goddess of Sicily, is only 480 miles in diameter and is not visible to the naked eye even under the very best of conditions.

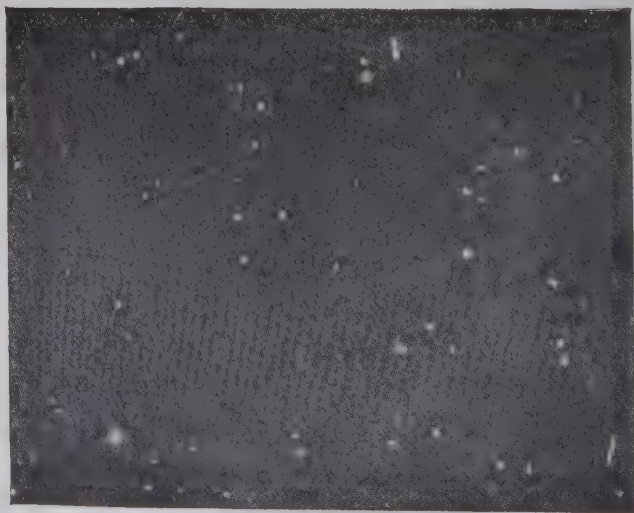


Fig. 15. Three minor planet "trails" during a three-hour exposure. The stars have no trails and appear as stationary dots

Soon after Piazzi's discovery another small planet was accidentally found when the position of Ceres was being measured. Between 1804 and 1807 two more were added to the list, and since that time more and more of these minor planets have been discovered until now there are over 1,400 on the "permanent list" with over 1,000 "possibles" awaiting further investigations. Vesta, discovered in 1807, is the only asteroid ever visible to the naked eye. Every year additional minor planets are added, and it is estimated that there are at least 30,000 within range of our present telescopes. It is probable, however, that many of these objects do not deserve the name "planet," being nothing more than large masses of rock circling around the sun, each in its own particular orbit.

PHOTOGRAPHY AIDS DISCOVERY

The large number of these planets discovered is accounted for by the fact that most of them have been discovered by photography, by which means their detection is rendered comparatively easy. These planets have a movement of their own, as they circle round the sun, so that they

appear to make a trail on a photograph, whereas the stars appear merely as circular dots (Fig. 15). The most useful of them all is Eros, discovered in 1898 by Witt of Berlin. Although this tiny planet is only 20 miles in diameter, its importance exceeds that of all the others, it being used, as we have already mentioned, in measuring the distance of the sun.

It has been suggested that these minor planets may be the result of some stupendous explosion—that they are the fragments of some large planet that at one time occupied a position between the orbits of Mars and Jupiter. If this is the case it is mathematically certain that there must have been not one but many explosions—first in the original planet and then in separate pieces—for it has been clearly demonstrated that no single explosion could account for the complexity of the orbits of these objects. Another theory—regarded as more likely—is that the material that should have formed a large planet between Mars and Jupiter failed to unite because of the powerful attraction of Jupiter, the force tending to pull to pieces the large planet before it was completely formed.



Fig. 1. Path of a meteor (shown by white streak) across the sky. Photograph was accidentally made when plate was exposed to Andromeda Nebula (center)

CHAPTER 4

COMETS AND METEORS

EXACTLY why the mention of a comet should arouse such interest among the general public is not clear, for these objects are generally very much overrated as sky-show spectacles. Many comets are discovered every year, but the majority are insignificant and remain telescopic objects only, throughout their career. Seldom is it that there is a comet large enough to give such a brilliant display as was provided by Donati's comet of 1858 or the "Daylight Comet" of 1910.

In bygone times the appearance of a comet was a cause for considerable alarm, the superstitious regarding comets as "ominous of the wrath of heaven, harbingers of wars and famines, of the dethronement of monarchs, and the dissolution of empires." Yet no large comet appeared in 1914, when according to subsequent events, we reasonably might have anticipated the appearance of the largest comet in history! One good thing resulting

from the ancient superstitions was that accurate records were made of all comets. These records have been of the greatest service to historians and astronomers in fixing dates and identifying early appearances of those comets that return at regular intervals.

The Chaldeans seem to have regarded a comet as a kind of planet that revolved around the sun in so large an orbit as to be visible only when moving in that part of the orbit near the earth. In a sense, perhaps, they were not altogether wrong, at any rate so far as one class of comets is concerned, for it may be that these comets actually are composed of outlying portions of the original hypothetical nebula from which the solar system may have been formed, as we shall see later in this section.

Comets belonging to this class are known as periodic comets, for they belong to the solar system and revolve in elliptical orbits round the sun. In most cases these orbits go out

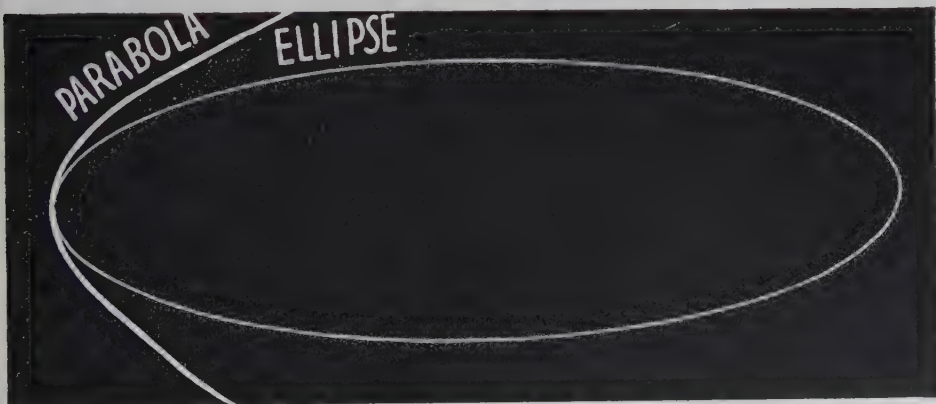


Fig. 2. The difference between the paths of solar or periodic comets (ellipse) and stellar comets (parabola)



Fig. 3. Morehouse's comet, as seen from Greenwich, October 3, 1908, showing its multiple tails. The short white lines are star trails

into space to distances of twenty or more times Neptune's distance from the sun. From this it seems evident that the material from which the solar system was evolved must have extended over this great volume of space. We shall refer to this again in our later section which deals with the beginning of the earth.

Some comets seem to have parabolic or even hyperbolic orbits. Since parabolas (Fig. 2) and hyperbolas are open curves, it is evident that a comet

having a parabolic or a hyperbolic path could visit our solar system but once. It is difficult to imagine a comet traveling away from the sun forever and forever. At present there is a growing belief among astronomers that all comets have orbits that are closed curves—those that were formerly thought to be parabolic being very long ellipses. Some of our ablest students of comets believe that all comets belong to our solar system.

STRUCTURE OF A COMET

There are two parts to a comet: the head, or nucleus, and the tail. Generally the heads of all comets are very similar in appearance, although varying in details of size and shape, and perhaps color. The tails, on the other hand, present wide variations—some are short and stumpy; others are long and curved. They may resemble the shaft of a spear, be curved like a scimitar, or may be twisted and broken. Sometimes there may be more than one tail—Comet Morehouse, which was seen in 1908, had six during part of the time it was visible (Fig. 3)—at others there may be no tail at all. The tail varies night by night, so that the appearance of the tail is no guide as to the identity of the comet (Fig. 5). Being of a tenuous nature, it may have an entirely different appearance at each return to the vicinity of the sun.

The tail of a comet is so tenuous that stars may be seen shining through it (Figs. 3 and 5), and for this reason Oliver Wendell Holmes called comets the "spectres of the heavens." A comet's tail always points away from the sun (Fig. 4), so that the general appearance of a comet is no indication of the direction of its motion. As we cannot rely on the physi-

cal appearance of a comet, the identification of any particular comet depends entirely on recognizing the orbit it pursues. At least three observations on different nights are necessary for a preliminary calculation, and a month's observations would give all the information required to compute the orbit with precision.

It is estimated that there are probably more than 120,000 comets in the solar system, but these are practically all invisible to the naked eye. Only once, in August, 1881, were two bright comets visible simultaneously in the same region of the sky. Seldom are more than half a dozen visible at any one time but in November, 1892, seven were to be seen. In 1939, twelve comets were seen, and this is the largest number ever seen in one year—recorded astronomical history offers no duplicate of this record.

HALLEY'S COMET

The most famous comet in history is that called after Edmund Halley (1656-1742). Halley assisted Newton in investigating the effects of gravitation on comets and he collected all the observations of comets he could find. Computing the orbits of 24 comets that had been observed in the years between 1337 and 1698, he found that three of them bore such a striking resemblance to each other as to suggest they were not three distinct comets, but three separate appearances of the same comet. The first had been recorded in 1531 by Apian and Fracastor; the second in 1607 by Kepler; and the third in 1682 by Halley himself.

Halley noticed that between each date there was an interval of about 75 years, and on looking up earlier records he found that a similar comet



Fig. 4. Twelve successive positions of a comet in its orbit round sun. Note how its tail always points away from sun

had been recorded in 1456. He came to the conclusion that this particular comet moved in an orbit that required about 75 years to complete. He then took a bold step by announcing that he could "with confidence predict its return in the year 1758. If this prediction is fulfilled," he said, "there is no reason to doubt that the other comets will return." Halley could not hope to live to see his prediction fulfilled but he hoped that "if the comet should return . . . impartial posterity will not refuse to acknowledge that it was first discovered by an Englishman."

Although Halley had been dead for some sixteen years when the comet was due to return, his words lived after him. As the year 1758 drew near,

mathematicians commenced an investigation, on the assumption that Halley was right, into the perturbations of his comet's orbit due to the attraction of Jupiter and Saturn, the chief disturbing factors because of their comparatively large masses. These investigations required the computation of the distance of the comet from Jupiter and Saturn not only in 1682 but during the previous appearance also. It was necessary to find exactly what disturbing forces were exercised by each planet over the long period of 150 years. The calculations were intricate and involved labor that occupied three leading mathematicians for six months. Only by great effort were they able to conclude the matter before the comet reappeared.

By the end of 1758 they announced that the comet's movement on this occasion would be retarded to the extent of 518 days by the attraction of Jupiter and 100 days by that of Saturn, or about 20 months in all. They predicted April 13, 1759 as the date of the comet's nearest approach to the sun. As this date drew near astronomers searched the heavens diligently for the return of the wanderer, but it was left to an amateur astronomer named Paltzsch to discover the comet in 1758. The comet reached its nearest point to the sun on March 12th of the following year, a month before expected.



Fig. 5. Morehouse's comet on September 29, 1908. Notice marked difference in comet's appearance in four days, see Fig. 3

No comet could have a more interesting history—in the prediction of its return by an astronomer who knew he could not live to see the fulfilment of his predictions; in the mathematical calculations of the date of the closest approach to the sun being so nearly correct; in the rediscovery of the object by an amateur, whose brilliant work outshone that of the professional astronomers; and, finally, in the complete fulfilment of Halley's prediction. The comet once again, as in the case of Neptune and Pluto, bore witness to the triumph of mind, and the might of human thought which is able to solve some of the profoundest mysteries of the heavens—mysteries which captivated the imagination since time began.

In 1835 Halley's comet again returned and was found on August 5th by Domouchel, of Rome, close to the



Fig. 7. Halley's comet as seen from Yerkes Observatory on May 4, 1910

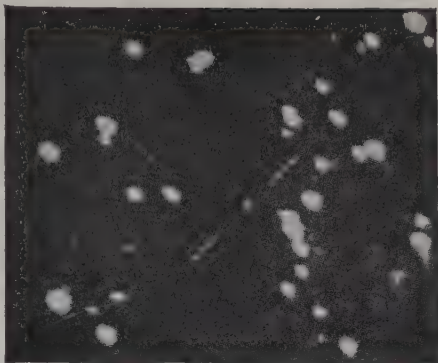


Fig. 6. Discovery Plate of Halley's comet, which is seen as a dot between two white lines near the center of the picture

place assigned to it. When the comet was first observed it was seen as a faint misty object that could be discerned only with difficulty, but later it was visible to the naked eye developing a tail 25° in length, or about fifty times the breadth of the full moon.

THE COMET'S LAST RETURN

In 1910 Halley's comet again returned, but for a long time it could not be found, even though photography was now available to assist in the search. As night after night passed without any trace of it, the question arose as to whether it had been subjected to some unknown influence in the depths of space so that its orbit had been changed, or alternatively, whether at last it had become "worn out" or disintegrated. On September 11, 1909, however, all doubts were set at rest when its image was found on a negative exposed by Dr. Max Wolf of Heidelberg (Fig. 6). It was a very faint object indeed but was discovered close to the place where its reappearance had been predicted. Although it

was not seen well from the northern hemisphere, in Africa and Australia it was a magnificent object with a broad tail some 90° in length. It looked "like the rays of a powerful searchlight, so long that it reaches from the horizon to the very roof of the heavens" (Fig. 7).

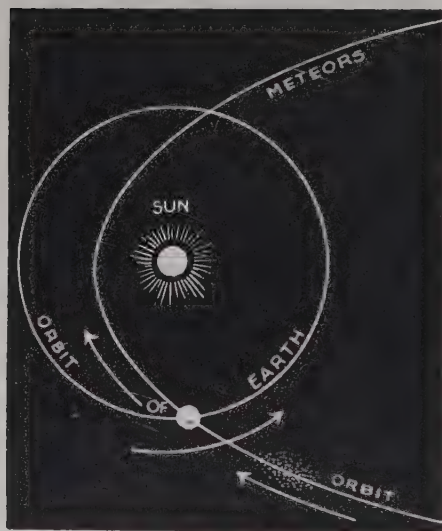


Fig. 8. How the earth's nearly circular orbit sometimes crosses the elliptical orbit of meteoric bodies

Working backwards through history it has been found that Halley's comet can be identified as having returned regularly at intervals of between 74 and 79 years—the differences being due, of course, to the perturbations caused by Jupiter and other planets—to as far back as the year 11 B.C. On this particular occasion the comet was recorded by Dion Cassius as having been apparently suspended over Rome before the death of Agrippa. In A.D. 66 the comet was recorded by Josephus, who regarded it as a warning foretelling the destruction of Jerusalem. In the year 451 the comet was

seen about the time of the Battle of Chalons at which Attila, leader of the Huns, was defeated by the Roman general Actius. The comet's most interesting appearance, however, was that of April, 1066, when its remarkable appearance attracted attention all over Europe. The success of William the Conqueror and the death of King Harold subsequently were attributed to its influence by the superstitious. Its appearance on this occasion has been immortalized in the celebrated Bayeux Tapestry, worked by Queen Matilda, depicting events of the time.

The probable composition of comets is connected with the question of "meteorites" or "shooting stars." Nearly everyone has seen at some time or another what is called a "shooting star" suddenly flash across the sky as a streak of light, to disappear as silently as it came. It seems as though one of the mighty stars of heaven has fallen from its place, but were we to count the stars immediately thereafter we should not find one missing. These objects are not falling stars—they have a more humble origin. The phenomenon actually takes place in the earth's atmosphere and not in the heavens beyond.

There are multitudes of small bodies circling through space, each in its own orbit and obeying the same laws of gravity as do the planets and other heavenly bodies. Sometimes one of these objects approaches the earth, or the earth crosses the orbit in which these bodies are traveling near to the point they have just reached (Fig 8). When they enter our atmosphere they are heated to incandescence by the intense friction caused by their passage through the air. We see them only when this occurs, as until they

enter the atmosphere they are invisible. They have a friction temperature of over 7,000° F., and as they flash through the atmosphere we see them as streaks of light, which sometimes leave luminous trains.

SHOOTING STARS

Some of these shooting stars, or meteors, may be seen on any clear night and are probably just as numerous in the daytime. Hundreds of millions are captured by the earth's atmosphere every day, but the majority are too small to be seen. The capture is due, of course, to the gravitational pull which the earth exercises. With a few exceptions they are dissipated before they reach the earth and form very fine meteoric dust that is visible with a microscope as tiny metallic globules—like microscopic shot—beside which sand grains appear to be blocks of rough stone (Fig. 9).

On certain nights more meteors are visible than on others, owing to the fact that these objects travel round the sun in streams, and on these nights the earth crosses or approaches such a stream. These streams result from the gradual drawing out along their orbits of the individual members of a swarm of meteoric bodies. On certain nights the earth regularly crosses various meteor streams as it pursues its journey round

the sun. The dates each year when this occurs are well known, the most familiar being that of November 13th, on which night in 1833 there was probably the finest shower of meteors ever seen. It was remembered that a similar display had been seen in 1799, thirty-four years before, and records showed that a similar shower had been seen at intervals of thirty-three or thirty-four years for at least 1,000 years.

THE LEONIDS

When the paths of the 1833 meteors were traced in the sky it was found that they seemed to radiate from the constellation called Leo, and for this reason this particular shower is called the Leonids. The return of the Leonids was confidently predicted for

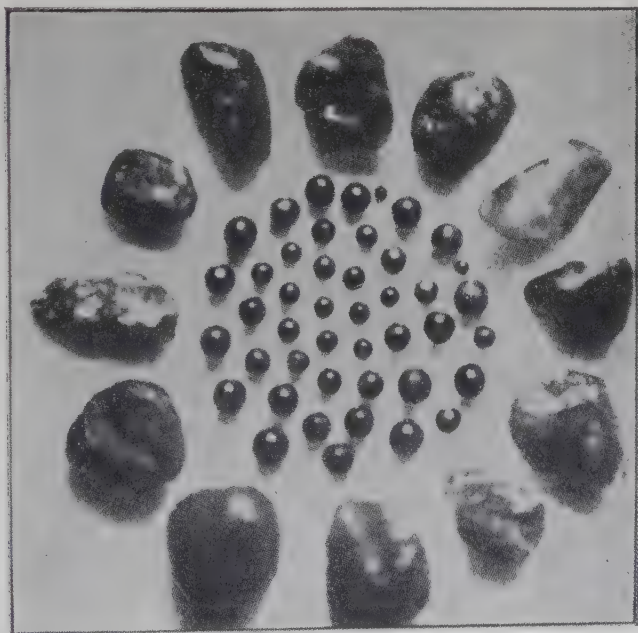


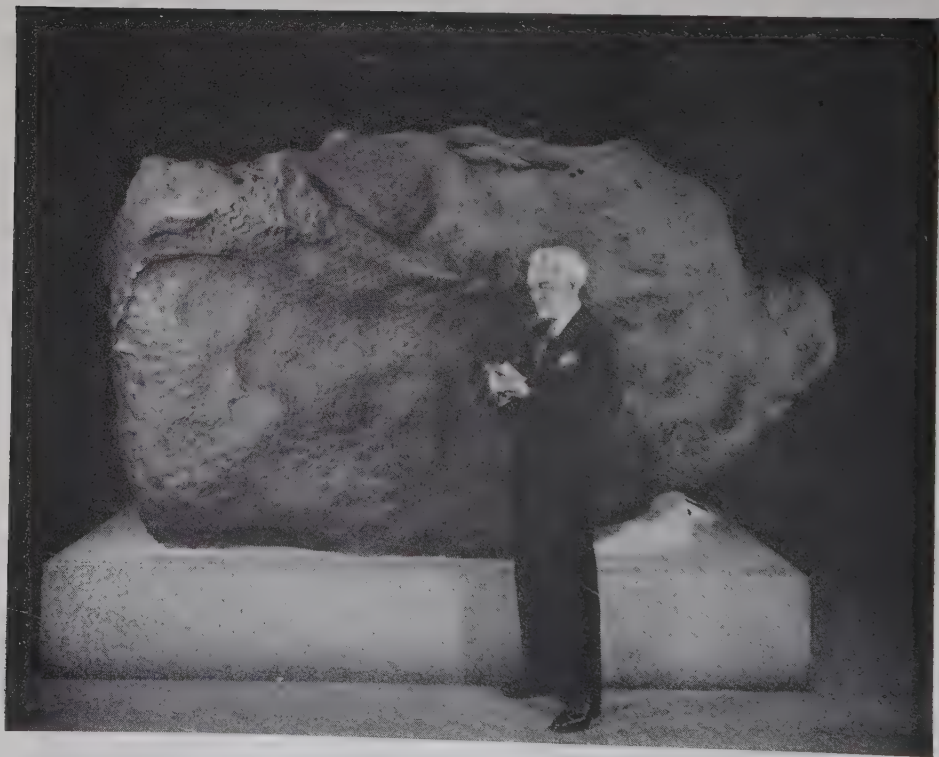
Fig. 9. Meteoric iron dust (small spherical objects in center) seen through microscope compared with grains of sand (outer ring)

1866 and again an impressive spectacle was seen, but in 1899 they did not come up to expectations—indeed, they failed to appear at all. Something had happened to the stream, but exactly what is a mystery. The most likely explanation seems to be that the orbit of the stream was altered by the attraction of Jupiter. Although some Leonids are seen every year about November 13th, we do not know in what year the earth will again pass through the main swarm, if ever.

Although the majority of meteors are dissipated by friction with the atmosphere before they reach the earth's surface, there have been occa-

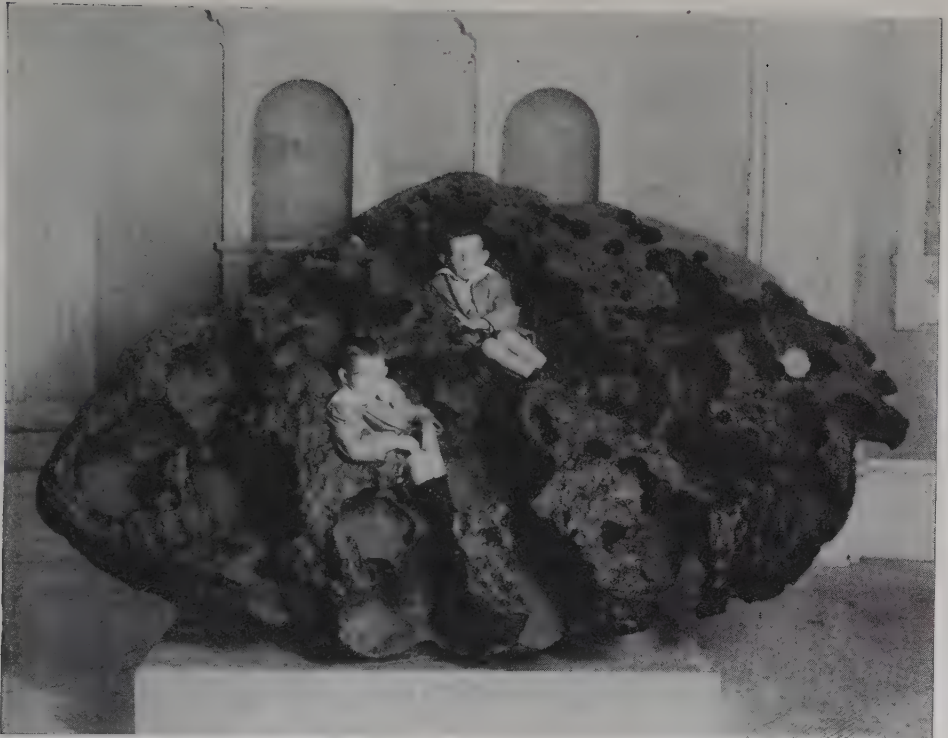
sions when some—perhaps larger than the majority—have managed to penetrate through the atmosphere to the earth.

Meteors, when as bright or brighter than Venus, are usually called *fireballs*. When they explode in the earth's atmosphere they are called *bolides*. Meteors that penetrate the atmosphere all the way to the earth's surface, are called *meteorites*. Meteorites are divided into iron meteorites, called *siderites*; stone meteorites, called *aerolites*; and intermediates between the two. Superb collections of meteorites are to be seen in the United States National Museum in Washington, in the Field Museum of



American Museum of Natural History

Fig. 10. Dr. Clyde Fisher stands beside the 36½-ton Ahnighito, a meteorite from Cape York, Greenland



American Museum of Natural History

Fig. 11. The Willamette Meteorite, taken from Willamette, Oregon, weighs about 16 tons

Natural History in Chicago, and in the American Museum of Natural History in New York. Specimens of the latter institution are seen in Figs. 10 and 11.

No two meteorites have the same composition and some fifty different types are recognized. Metallic meteorites are about nine-tenths iron. All metallic meteorites contain nickel, and many contain cobalt. While some contain kamacite and others schreibersite, there are some in which there are no traces of metal. Very small diamonds have been found in some, such as in the Canyon Diablo meteorites of Arizona. Tektites, such as the "Australites" found in Australia are at-

tributed to unique showers of glass meteorites.

METEORIC BODIES

The majority of meteoric bodies that have at different times reached the earth have done no harm as they have not fallen on human habitations. On a few occasions there have been more startling occurrences, however, which give us some indication as to what might happen and what damage might be done by the fall to earth of a very large meteorite, or by an aggregation of large groups of these strange and curious celestial bodies.

An enormous meteorite lies near Grootfontein, in South-West Africa. It measures 10 ft. by 10 ft. by 4 ft.

and weighs about 70 tons. When it struck the earth the impact must have been terrific, for it made a hole 5 ft. in depth in the limestone rock on which it fell. Analysis of this meteorite shows that it contains 6 per cent nickel and is so tough that two hours' work and a dozen hacksaw blades were required to cut off a small piece. This meteorite, called the Hoba, is the largest meteorite known in the world.

In 1908 a huge swarm of meteorites fell near the Tunguska River in Northern Siberia, where an area of several square miles looked as though it had been subjected to a bombardment by heavy artillery. Millions of trees were destroyed and craters, like wartime shell holes, up to 150 ft. in diameter and 12 ft. in depth, were formed in the ground. The light produced by the fall was seen by passengers on a Trans-Siberian Railway train, and the roar was heard 400 miles away. The accompanying air wave was recorded as far away as Cambridge, in England, although at the time its cause and origin were unknown.

It was a prehistoric fall that resulted in the formation of the meteor crater in Arizona, twenty miles west of Winslow. Here in a vast stretch of desert country is an enormous circular depression, nearly four-fifths of a mile in diameter and nearly 600 feet deep (Top, Fig. 12). Some years ago pieces of meteoric iron were found in the vicinity and this discovery resulted in the idea that this great crater was the result of the fall to earth of a gigantic mass of meteoric iron. A close study of the formation resulted in confirmation of this theory, for it was found that although the upper part of the rocks in the district are laid horizontally there are many

large masses that are standing vertically (Fig. 13). Then again, the rocks inside the depression have been shattered and the fragments strewn in all directions. Some of the softer rocks have been ground to powder, and much debris—evidently from the layer of rocks that covered the site of the depression—is scattered about outside the crater, mixed with meteoric iron. So much meteoric iron has been collected around this spot that the number of pieces, but not the quantity, exceeds that collected from the whole of the earth's surface.

It is now believed that the depression is due either to a closely packed swarm of meteors or a comet that collided with the earth (Fig. 12). Basing their calculations on the penetrative effects of shells from heavy artillery, experts have calculated that to have formed such a hole the mass must have weighed at least 10,000,000 tons. Some astronomers have therefore suggested that the mass in question may actually have been the head of a comet.

DIGGING FOR METEORIC IRON

It seems that the meteoric iron must be buried in the depression, and as the metal must be of considerable value—it contains nickel and the rare metals platinum and iridium—attempts have been made to excavate it. So far these attempts have been unsuccessful, despite the sinking of 29 bore holes, because these were sunk vertically, it having been assumed erroneously that the meteorite entered the earth on a vertical plane. The bore holes went down deep into a bed of hard red sandstone evidently not reached by the meteorite because no fragments of this rock were thrown out on the surrounding surface.

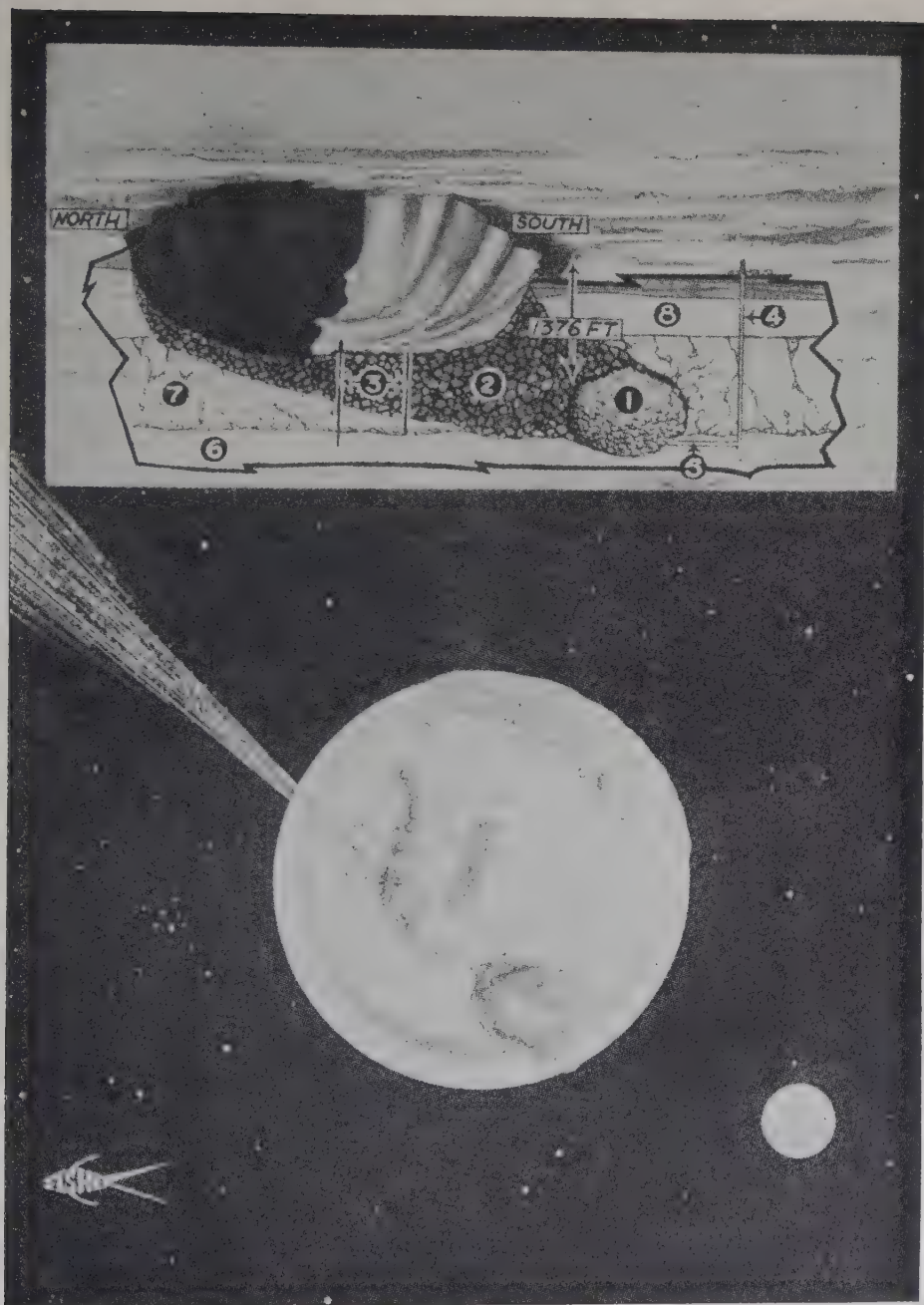


Fig. 12. The great meteor crater of Arizona. (1) Supposed position of meteorite. (2) Shattered rock. (3) Early borings. (4) New shaft. (5) Proposed tunnel. (6) Hard red sandstone. (7) White Coconino sandstone. (8) Kaibab limestone

A new examination of the matter suggested that the meteorite did not plunge vertically to earth, but at an angle, and that therefore the mass would be lying not below the center of the crater but beneath the rim. Further observations of the crater confirmed this idea, for it was noticed that on the southern side the amount of material thrown out was greater than at any other point, and it was also seen that part of the southern rim had been lifted 100 ft. From this it is believed that the meteor approached from the north and buried itself under the southern rim, heaving up the strata above. A trial bore

was therefore made from the southern rim and at 1,200 ft. broken sandstone and fragments of meteoric iron were brought up, the proportion of iron increasing until at 1,376 ft. the drill became permanently stuck. Just before further drilling became impossible, three-quarters of the material brought up was oxidized iron of meteoric origin. Such a quantity could not have penetrated to this very great depth unless it was an integral part of an enormous mass, and there seems little reason to doubt the fact that the abandoned drill is in direct contact with the actual meteorite itself (Fig. 12).



Fig. 13. An originally horizontal rock on the edge of Meteor Crater, forced vertical by the impact. Comparison of horse in lower left of picture indicates the huge mass of rock displaced

As to when this great body collided with the earth we have no means of knowing with certainty. The crater has certainly been there for over 700 years, for a tree growing on its edge showed by its annual rings that it had been growing for that length of time. Considering all the evidence, it is estimated by Professor Eliot Blackwelder of Leland Stanford University that Meteor Crater was formed between 40,000 and 75,000 years ago, long before any Indians lived in that part of the country. The great Meteor Crater of Arizona remains one of the mysteries and marvels of science.

Although Meteor Crater in Arizona is the largest known in the world, it is not unique. There is a much smaller one near Odessa, Texas; a still smaller one near Haviland, Kansas (three known in United States); a group of thirteen craters near Henbury in Central Australia; the Boxhole crater in Central Australia; a group of seven craters on the Baltic island of Saaremaa (Oesel) belonging to the U.S.S.R.; the Wabar craters in Arabia; and the Siberian craters. Besides these there are a number of doubtful craters that may prove to be of meteoritic origin—one at Ashanti in West Africa, one in

Persian Beluchistan, the Campo del Cielo craters in Argentina, and a very doubtful group near the coast of South Carolina.

That meteors and comets are closely connected is now generally accepted, a remarkable similarity between their orbits having been noticed many years ago. For example, Tempel's comet of 1866, which has a period of 33 years like the Leonids, is connected with them. The Perseids, which are seen in August, have been shown to be connected with Tuttle's comet which appeared in 1862. The orbit of Biela's comet—which split in two in 1846—coincides with that of the Andromedid meteors.

It is now supposed that meteors may be the products of the dissolution of comets, and that they consist of minute particles disintegrated from comets along their orbits, such disintegration being caused by the forces of the sun and the planets acting on the materials of which the comets are composed. The nucleus of a comet, probably consists of a swarm of meteors, surrounded by a cloud of gas, debris, and dust, on which the sun acts, causing a stream of gas to be thrown out which forms the tail.



Fig. 1. Orion Nebula photographed through the 24 in. reflector at Yerkes Observatory

CHAPTER 5

THE STARS

WHEN discussing the discovery of Uranus by Herschel we mentioned the difference between a planet and a star as seen in the telescope, pointing out that a planet always presents a definite globelike disc, whereas a star appears as a twinkling point of light. There is as vast a difference in the physical constitutions of the two bodies as in their appearances, for the planets are mere worlds revolving around the central sun, and with comets and meteors forming what we call the solar system. On the other hand, all of the numerous stars that dot the heavens are actually suns, and our sun is a star like them—indeed, it would appear as such could we journey into space even as far as Pluto, the outermost

planet. If we continued our travels further the sun would grow fainter and fainter, until but a tiny speck merged into the cloud of other stars in the system to which it belongs. This system in turn is only one of many other similar star systems, "other universes" they are sometimes called, scattered loosely and abundantly about the heavens.

Many of these other suns—the stars—are larger and brighter than our sun, some of them enormously so. They vary in size according to their color, the red stars being larger than the blue stars. To mention the size of these stars in miles, or to express their weight in tons, makes little impression, as we cannot comprehend figures so gigantic. A better illustration,

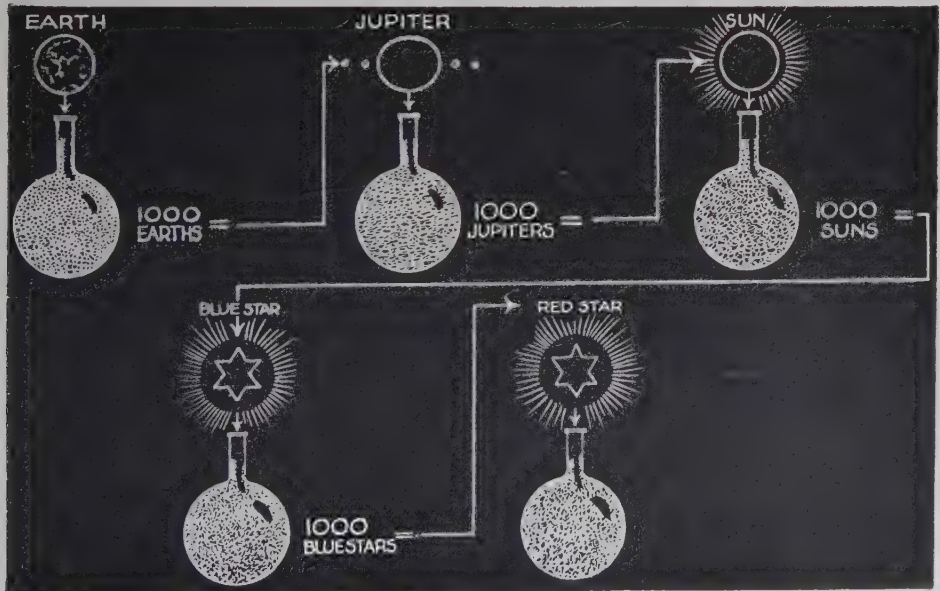


Fig. 2. A diagram illustrating the relative size of the earth and some of the stars

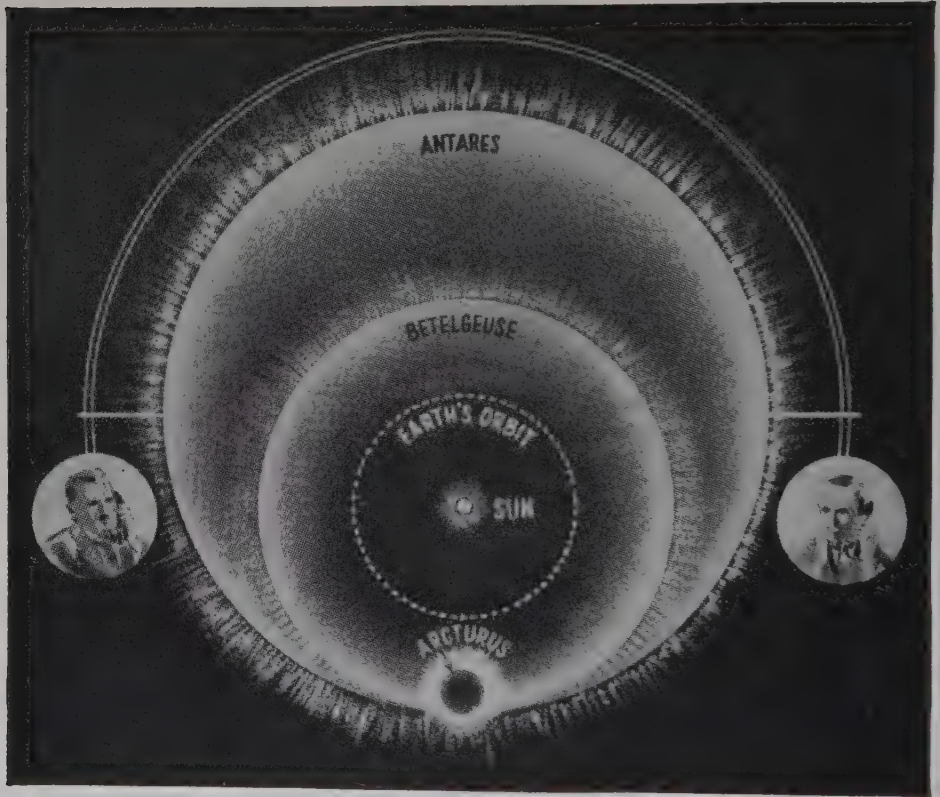


Fig. 3. Antares, Betelgeuse, and Arcturus compared with size of earth's orbit. Antares is so big that an electric current would take 53 minutes to pass half way round the star. Betelgeuse is a pulsating star, and when largest is much larger than Arcturus

perhaps, may be given by a progressive consideration based on the size of the earth. We have already mentioned that the planet Jupiter could contain more than 1,000 planets the size of the earth. Now, the sun similarly could contain over 1,000 planets the size of Jupiter. In the same way, each of the larger blue stars could contain 1,000 globes as large as the sun, while the largest stars, the red ones, could contain 1,000 blue stars. In Fig. 2 the artist illustrates these facts diagrammatically by use of chemical beakers.

Fig. 3 illustrates the comparative sizes of three stars in relation to the sun. Arcturus, *Alpha Bootis*, seen at the bottom of the drawing, is the third brightest star north of the Celestial Equator. Arcturus is over one hundred times as bright as the sun and is about 40 light-years distant from us. (The term "light-year," a term scientists always use to describe astronomical distances, is explained on page 76.) Betelgeuse, *Alpha Orionis*, is a red giant situated about 270 light-years distant. It is over 1,200 times as bright as the sun

and over three hundred times its diameter. As the diagram clearly shows, if Betelgeuse were hollow it could easily contain not only the earth and the sun, but also the entire orbit of the earth.

Also shown in comparison is another great red giant, Antares, *Alpha Scorpii*. Situated at a distance of over 160 light-years, Antares has 4,000 times the candlepower of the sun, and is over 450 times its diameter. Its mass, of course, is some hundreds of thousands that of the sun. Electricity, like light, travels at over 186,000 miles a second, so that an electric current will travel seven times around the earth in a second. So huge is Antares that it would require 53.3 minutes for an electric current to travel halfway around this star.

Whether any of these suns—the stars—have planets circling around them we cannot tell, for their distances are too great to render visible planets even as large as Jupiter. What we do know, however, is that a large proportion of them have a companion sun—that is, they are double stars.

The fact that our sun is some 700 times more massive than the combined mass of the planets of the solar system is rather a remarkable feature, and appears to be an exception. In many thousands of cases the stars consist of a system of two or more stars of approximately equal size. With every increase in the size of telescopes, more and more stars have been shown to be doubles. In numerous cases, too, where the telescope does not show this, another instrument—the spectroscope, with which we shall deal in a later section—demonstrates the double nature of companions too close to be shown separately by any telescope.

STARS THAT CHANGE COLOR

Even to the naked eye it is apparent that the stars differ in color—Arcturus is yellow; Vega, blue; Aldebaran, red; and so on. There seems little doubt, too, that stars change their colors in the course of time. Both Ptolemy and Seneca declared that Sirius was of a reddish hue. Now, 2,000 years later, it is definitely white. Another star in Leo (*Gamma Leonis*) was white in Herschel's time but now is golden yellow. A century ago Sestini described the two components of a star in Hercules (95 *Herculis*) as both golden yellow, but shortly afterwards one turned apple-green, and the other cherry-red. Many of the stars in the multiple systems referred to above display remarkable color contrasts—whites, yellows, and blues. Many pairs have totally different colors—green and red, orange and blue, yellow and purple, and so on.

If we ask anyone how many stars we can see on a clear night with the naked eye we should probably be told "Oh! millions." That is the general impression, yet it is an amazing fact that on a clear night a person with average sight can see only about 3,000 stars! Those who have exceptionally keen sight can see about 3,500 or 4,000 at the most. But there are many more stars than this in the heavens: even a small telescope is capable of showing 120,000.

THE NUMBER OF STARS

With our largest telescopes the number that may be seen visually is increased to 80,000,000, and those fitted for photography will record many more. The total number of stars that can be photographed by the 100-in. Mount Wilson reflector—at

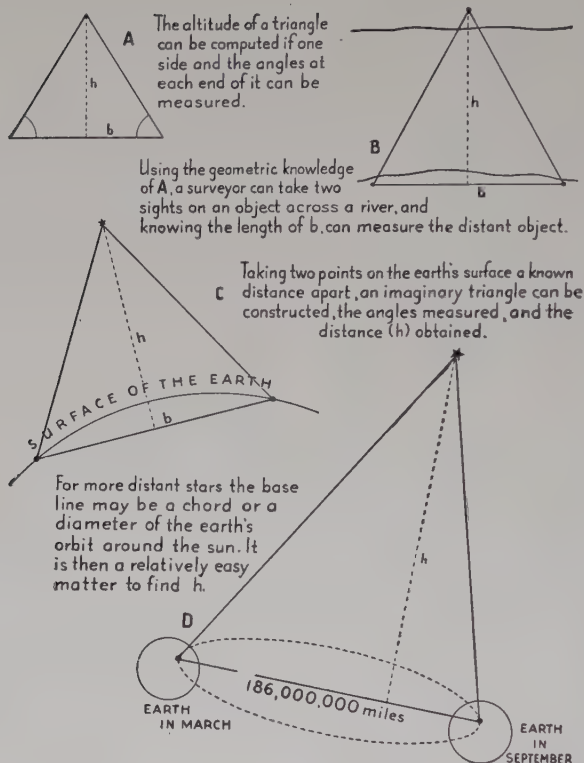


Fig. 4. How parallax enables us to determine the distance of a star. Using the diameter of the earth's orbit as a base line, the apparent shift of position in relation to a more distant star is measured

present the world's largest telescope—is 1,500,000,000. As in the case of the celestial measurements of size already mentioned, the colossal number of stars, each one a sun, is indeed awe-inspiring and quite beyond our powers of comprehension. No known mechanical device could even remotely suggest the magnitude of our universe.

We have already seen how the distance of the sun is measured. Great though this distance is, it is insignificant when compared with the distances even of the nearest stars. When considering parallax we found that

the distance between our eyes is not sufficiently great to enable us to obtain a parallax of a distant object, although quite satisfactory when applied to objects close at hand. In the same way, the base line provided by two observatories at opposite sides of the earth is too small to show a parallax where the stars are concerned. A much longer base line is necessary, and this is provided by the orbit of the earth. The position of the star to be measured is determined, say, in March, and is then measured again in September. In the meantime the earth has completed half a revolution in its orbit around the sun, and is at the other end of a gigantic base line of nearly 186,000,000 miles (Fig. 4). If a difference is shown in the star's position in the sky, as compared with that

of a more distant star, its distance from the earth can be found.

Even the gigantic base line thus provided by the earth's orbit is all too small, for the distances of the stars are so enormous that the resulting parallaxes are concerned with extremely minute quantities. No star has a parallax as great as 1" (one second of arc) and that amount is equal to the angle subtended by a man 6 ft. in height at a distance of 250 miles! The nearest star, *Proxima Centauri*, a faint star near one of the brightest stars in the southern sky, has a parallax of .79 of

a second of arc, corresponding to a distance through space of 25 trillion miles.

THE "NEAREST" STAR

An interesting illustration may enable us to judge of the immensity of this distance. The fineness of the spider's web is too well known to require elaboration. A quantity of 1 lb. of it would be sufficient to encircle the earth at the equator. A line could be stretched from the earth to the moon with 10 lb., and to the sun with 3,712 lb. To reach *Proxima Centauri* would require no less than 500,000 tons!

When measurements of distance are made photographically, on negatives taken of the same region of the sky at an interval of six months, the "shift" of the star under observation is noted in regard to other nearby stars recorded on the photographic plate. A microscope must be employed to determine these measurements, as the quantities to be measured are rarely more than a few hundred-thousandths of an inch. Fifty or sixty years ago the Astronomer Royal of the day referred to one-tenth of a second of arc as "the smallest thing in the world." Today, skillful observers using large telescopes are able to measure parallaxes of 16-thousandths of a second of arc. Beyond this extraordinarily fine limit errors of observation may amount to as much as the parallaxes themselves. The observatories which do the greatest amount of the parallax work—that is, measuring the distances to the stars—are the Leander McCormick Observatory at the University of Virginia, and the Allegheny Observatory of the University of Pittsburgh in Pennsylvania.

Expressed in mere miles the distance of *Proxima Centauri*, the nearest star—some 25,000,000,000,000 miles away—conveys nothing even to the mind of an imaginative person. To express such distances more conveniently, therefore, the speed of light has been used in the following way.

That sound takes an appreciable time to travel over a given distance may be demonstrated without great difficulty. For instance, at a football game when the ball bounces we may not hear the noise it makes contacting the ground until it is several feet in the air on the rebound. Again, if we see a gun fired a short distance away, we first see the puff of smoke but we do not hear the report from the discharge until a few seconds afterwards, the length of the interval depending on our distance from the gun. Similarly, as sound takes time to travel through the atmosphere, so does light take time to travel through space. Sound travels at about 1,100 ft. a second but light is infinitely more swift, traveling at some 186,000 miles a second—the same speed, incidentally, as that of a radio wave, which travels seven times around the earth in a second. At this speed light takes about $1\frac{1}{4}$ seconds to reach us from the moon, and eight minutes from the sun. From the nearest star, *Proxima Centauri*, it takes over four years to cross the intervening gulf of space. Thus, were this star actually to cease shining today, it would continue to be visible to us for another four years or even more.

THE SPEED OF LIGHT

The speed of light may thus be conveniently used as a kind of "celestial yardstick" to indicate the distances of the stars, and the dimen-

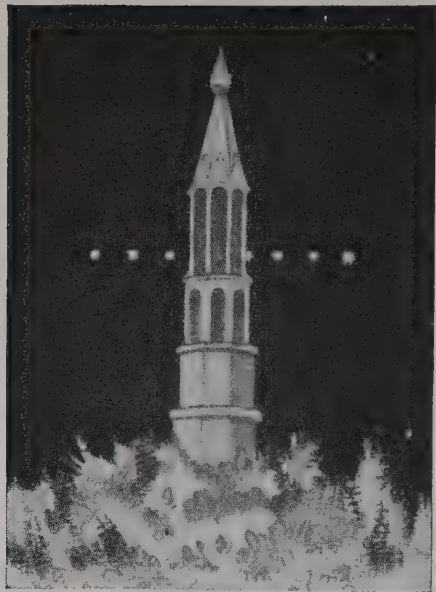


Fig. 5. How a star changes its position in relation to terrestrial objects in the course of a few hours, owing to the rotation of the earth. You can demonstrate this with an ordinary camera. (See text for explanation)

sions of the universe. Measurements by this celestial yardstick are expressed in "light years," for in a year light will travel about 6,000,000,000,000 miles. By this method of reckoning *Proxima Centauri* is said to be $4\frac{1}{3}$ light-years distant. Sirius, the brightest star in the heavens and visible in the south during the winter, is 8.8 light-years distant; Vega, the bright blue star in the constellation of Lyra, is 26.5 light-years distant. Arcturus is nearly 40 light-years; Betelgeuse, the red star in Orion, is 270 light-years away; the stars of the Pleiades are 500 light-years distant; and Rigel, the blue star in Orion, 540 light-years. The globular cluster of stars in the constellation of Hercules is 36,000 light-years away.

Those who care to do so can easily work out the actual distances in miles by multiplying these figures by $186,000 \times 60 \times 60 \times 24 \times 365$ —and the inclusion or omission of leap years will not greatly affect the resultant mileages!

The brightest stars were given names and the stars were divided into groups, or constellations, in very early times. The constellations resulted from the fancied resemblances of groups of stars to warriors, animals, or other objects on the earth, just as children imagine that they can see "pictures in the fire." Many stars and constellations are named after the heroes of the great legends of antiquity. To take classical mythology, for instance, both Perseus and Andromeda are immortalized in the heavens, as also are Cepheus and his wife Cassiopeia—the parents of Andromeda—and the Dragon. In this case, of course, these constellations mentioned represent figures in Greek mythology.

THE EARLIEST ASTRONOMERS

Although it is not definitely known when, or by whom, the constellations were named in the first instance, it is believed that they were mapped out at least as early as 4000 B.C. There is no doubt that the work was originally done by a people who lived near the Valley of the Euphrates, for—just as we know that the Great Bear cannot be seen from Australia, nor can we in the northern hemisphere see the Southern Cross—it is only from this locality that all the constellations named by the ancients can be seen. Probably the people concerned were the Chaldeans, from whom the system of grouping the stars spread to Babylonia, thence making its way

through Greek influence to India and the distant East. Although we do not know exactly how many constellations the Chaldeans named, they appear to have named the constellations of the zodiac and probably the forty-eight constellations recorded by Ptolemy.

Because of the rotation of the earth on its axis, the constellations appear to rise and set, and move across the sky exactly as the sun and moon do. We can see the extent of this movement by noticing at any given moment the position of some bright star in relation to some building or church steeple. Checking this an hour or two later it will be seen that the star has moved appreciably (Fig. 5). Naturally the longer the interval between the two observations, the greater the movement. Anyone with a camera can test this by exposing a film for two or three hours, directing the camera to some bright stars. The resulting negative will show a series of star trails, marking the paths of the stars across the sky. If the camera be directed to the Pole Star, these star trails will appear as arcs of circles (Fig. 6), since all the stars appear to revolve around a point near the Pole Star, as we shall explain later.

The sky should not be supposed to be above us as a flat surface, such as the ceiling of a room, but more as an in-

verted bowl. We shall get a better idea of the heavens if we imagine that the earth is placed at the center of a hollow globe, the inner surface of which is studded with stars. Naturally, an observer in the northern hemisphere cannot see the whole of the heavens from any one point in that hemisphere, but only that half that is above the horizon, the other half being visible to the people in the southern hemisphere.

THE POLE STAR

At the North Pole a bright star is seen directly overhead. This is Polaris, the Pole Star, towards which the axis of the earth happens to point. From the United States we do not see Polaris overhead because we are not "on top of the world," and it appears at



Fig. 6. How stars seem to move round the Pole Star. This time exposure shows how the images of stars appear as trails in great arcs round it. This is caused by the rotation of the earth on its axis

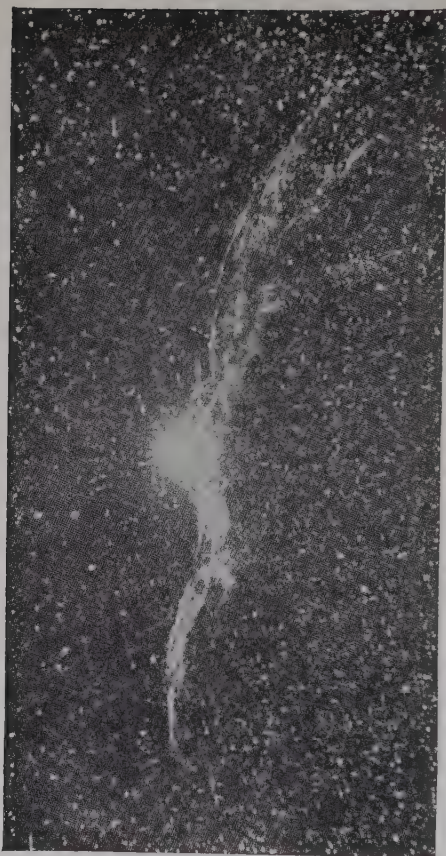


Fig. 7. The beautiful Bridal Veil Nebula of Cygnus, the constellation of the Swan. This is the well known gaseous nebula located inside our own Milky Way Galaxy

some distance lower—or to the north—of the point immediately overhead, which is known as the zenith. As we travel nearer to the equator, Polaris gets lower in the sky until we reach a point from which it is no longer above the horizon.

Because the axis of the earth points to near the Pole Star, all the constellations appear to revolve around it. Polaris is like the hub of a great wheel and the farther away a star

is from the hub the greater is its apparent movement through the sky. For instance, if there were a star 1° —that is twice the breadth of the full moon—from the Pole Star, it would have only a small circle of revolution around the Pole Star. A star 20° away would have a much greater circle to complete in the 24 hours.

The stars are in the sky during the daytime, but we cannot see them because of the overpowering light of the sun. As the light begins to fade at sunset the stars “come out,” and are seen with the naked eye in increasing numbers as night draws on. Bright stars and planets can be seen in daylight with a large telescope, because by it more of their light is gathered, so much more that they are visible in bright sunlight.

WHY STARS RISE AND SET

Owing to the earth's movement in its orbit around the sun, we see different constellations at different seasons of the year. The movement of the earth results in the stars rising, and, of course, setting, four minutes earlier in each twenty-four hours, this representing the amount by which the earth moves in its orbit in twenty-four hours. Thus if a star rose on March 1st at 7 p.m. and set at midnight, 60 days later (April 29th) it would rise at 3 p.m. and set at 8 p.m.—and for practically all that time would be obscured by the sun's brightness. Some of the constellations—those nearest the Pole Star—appear in the northern hemisphere all the year round, but others can only be seen in summer; still others can be seen only in winter.

As we shall see in our next section, dealing with the origin of the earth, it was formerly believed that the solar system originated in a huge nebula—



Fig. 8. The great Nebula in Andromeda, photographed with a 4-hour exposure, with the 24 in. reflector at Yerkes Observatory. This giant nebula which is really another universe far out in space is so vast that light takes 50,000 years to cross it

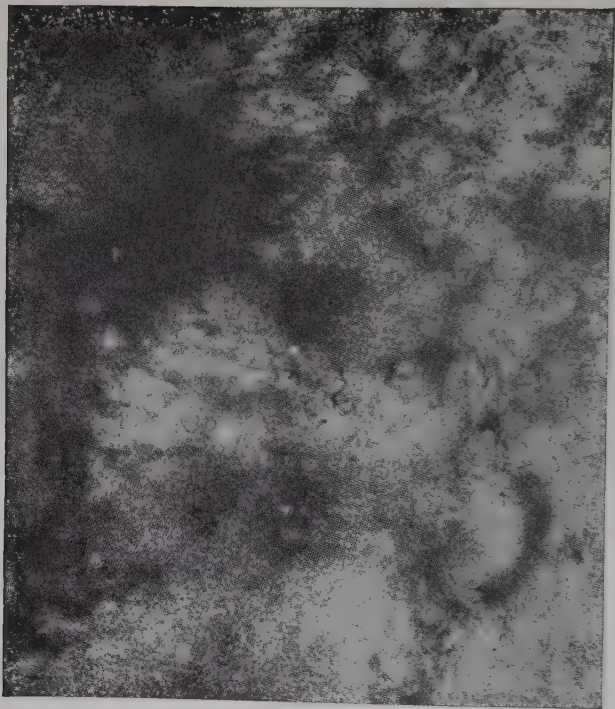


Fig. 9. The Milky Way near the star *Theta Ophiuchi* (almost in the center). Notice the numerous dark lanes seen at various points throughout the cluster

an immense cloud of "fire-mist" that extended in space to a greater distance than the diameter of Neptune's orbit. Similar nebulae may be seen in the heavens today and the number seen has increased with every increase in telescopic power.

In 1781, Messier, a French astronomer, catalogued 103 nebulae (a few of which proved, however, to be globular star clusters), and later Sir William Herschel recorded some thousands. The use of photography in the study of the heavens resulted in further thousands of new nebulae being added to the list until, with Professor Keeler's observations at the Lick Observatory, the number grew to 120,000. One illustration will serve to show

how photography has assisted in this matter, for when Keeler photographed a nebula in Pegasus he was amazed to find that on the resulting negative not only was the original nebula shown but no less than 20 new ones as well! Later the number of nebulae was increased to 300,000 by Professor Perrin's researches, also at the Lick Observatory. Today, the number of nebulae is estimated in millions, and they are of all sizes and shapes (Figs. 7 and 8). Hubble, at Mount Wilson Observatory, estimates there are 750 spiral nebulae to each square degree (the diameter of the full moon is equal to half a de-

gree) of the heavens, giving a total of 30,000,000 in the whole sky. The vast number of spiral nebulae, studied by Hubble, are now believed to be not gaseous nebulae, but great galaxies of stars far outside our Milky Way Galaxy. The Great Nebula in Andromeda is perhaps one of the most typical examples.

THE ANDROMEDA NEBULA

Perhaps the most wonderful of all is the Nebula in Andromeda (Fig. 8), which may be seen even in a small telescope and which looks like a tiny oval patch of bright light. Actually, it is comparable in size to our galaxy and is so vast that light requires 100,000 years or more to cross from

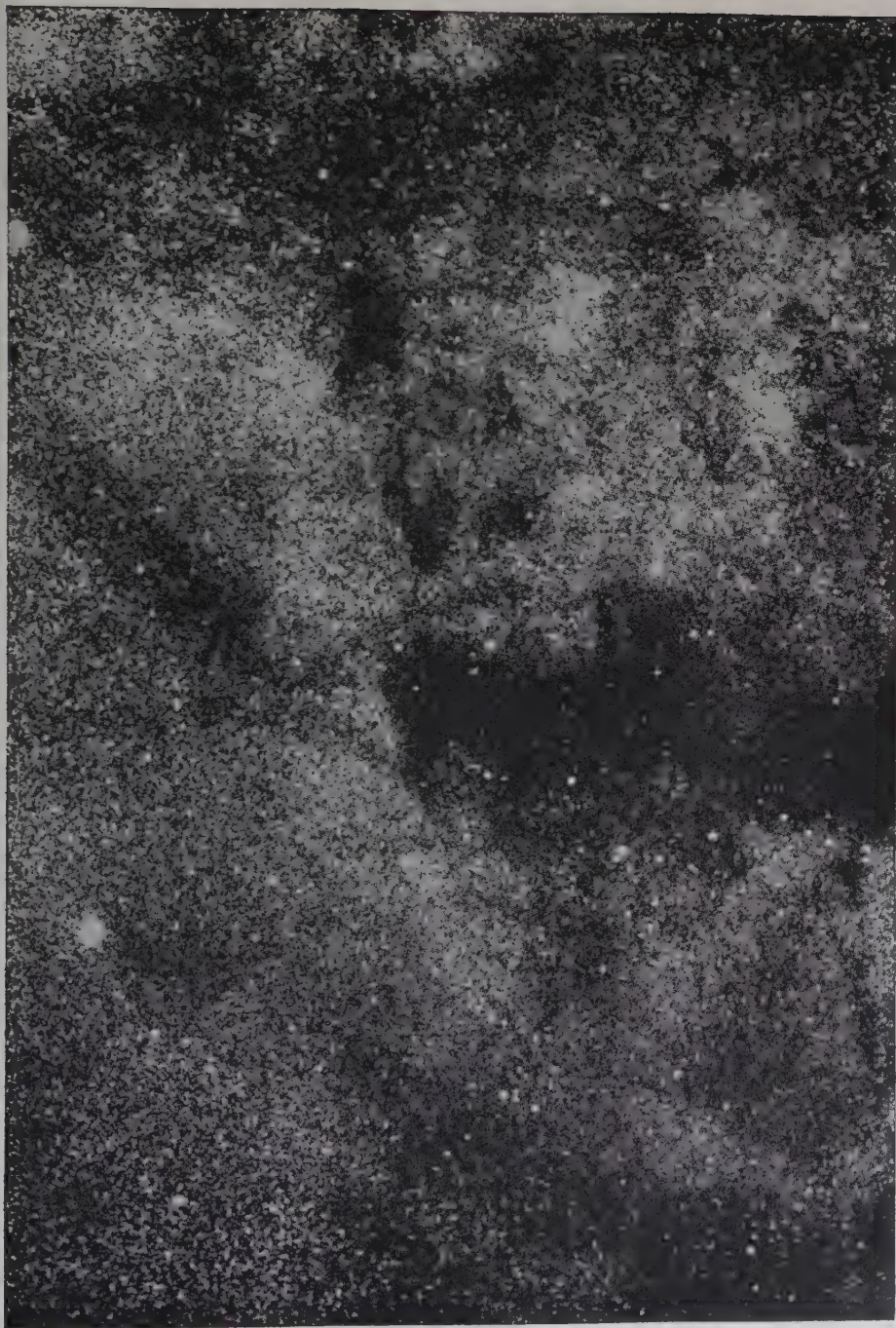


Fig. 10. Another picture of the Milky Way near *Theta Ophiuchi*, showing the Great Rift

one side of it to the other. Its distance is equally beyond our imagination, its light taking 680,000 years to reach us. At one time, it was believed that the spiral nebulae were solar systems in the making, and when Dr. Isaac Roberts, in 1888, obtained his famous photograph of the Andromeda Nebula it was widely publicized as showing what our own single star system was like in its early days. However, in 1925 Hubble succeeded in showing that at least part of the Andromeda Nebula consisted of stars. This led astronomers to conclude that all the spiral nebulae were not solar systems in the making but actually were other galaxies—other universes situated far out in space. The modern acceptance of this view means that our visible neighborhood has been expanded from a radius of 100,000 light-years to one having a radius of 500,000,000 light-years—a distance utterly beyond the powers of human comprehension.

THE MILKY WAY

The stars appear to crowd together towards that part of the sky known as the Milky Way, but the nebulae seem to be most numerous where the stars are fewest. To the naked eye the Milky Way appears as a band of misty light stretching across the sky—more distinct in some parts than in others. Photographs show that the Milky Way is actually composed of veritable clouds of stars (Figs. 9 and 10) the distances of which are so great that the eye cannot see them separately, so that only their combined light reaches the earth. On every photograph—and there are some hundreds—the stars are so numerous that they cannot be counted, and estimates have to be relied upon. These

vast numbers of stars are in wonderful formations of irregular clouds and sprays, exhibiting some remarkable features including lanes, holes, and enormous black gaps. These are well seen in Fig. 9, one near the center looking like the letter S. It is now believed that these mysterious markings are due to masses of black unilluminated nebulae which are interposed between us and the star clouds.

At one time it was believed that the sun was situated near the center of the Milky Way. Herschel suggested that the stars were arranged in the form of a disclike grindstone, and that the solar system was near the center. He pointed out that such an arrangement would account for the numbers of stars increasing towards the Milky Way, for here—according to this theory—we are looking through the length of the disc and consequently the stars appear to us to be more numerous. Later observations have not caused any radical alteration of this theory, and it would seem that our sun may be one of the stars that form one of the star clouds of our particular universe. It is not now supposed, however, that the sun is particularly near the actual center of the Milky Way; in fact it may be a considerable distance from it—about 30,000 light-years distant, it is thought.

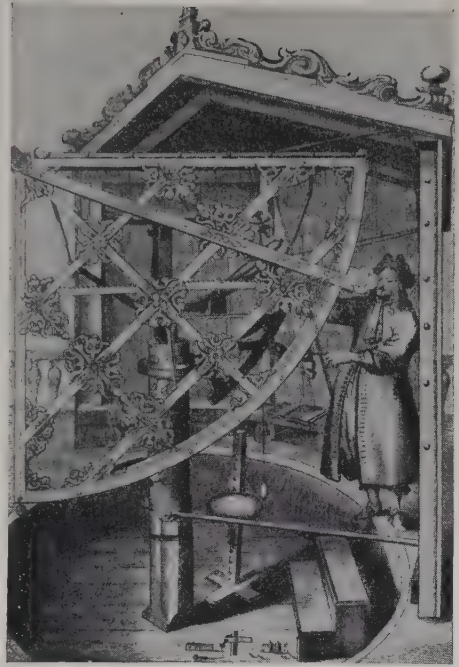
Although the stars seemed “fixed” in the sky, the constellations remaining identifiable for thousands of years, we know that this is not actually the case. The stars themselves are continually moving through space—some at tremendous speeds—but so vast is our distance from them that their positions do not appear to the naked eye to alter, even for a period as long as a century.

THE SUN'S VAST ORBIT

Our own star, the sun, is no exception to the general rule, for with its attendant planets it is moving through space at a speed of 200 miles a second, traveling around the center of gravity of its cosmic system. At this speed it requires 220,000,000 years to complete a revolution in its gigantic orbit. How many times the sun has circled its orbit cannot be determined or even accurately estimated. According to some authorities it must have made thousands, and perhaps hundreds of thousands, of complete revolutions.

As to the possibility of our sun colliding with some other star as it flies through space, there is little need for apprehension. If a map were made of the solar system, on which the orbit of Pluto, the outermost planet, was 1,500 ft. in diameter, the earth would be represented by a period, thus . On a map of the known universe measuring 15 miles square, the whole solar system would be represented by a similar dot. Thus we see that there is a vast space in which the stars can move with little possibility of any collisions occurring between them.

In the constellation of the Great Bear—actually in the part known as the Great Dipper—is a speck of light beyond the range of the naked eye. By means of our large telescopes this object is shown to be a strongly concentrated cloud of sixty nebulae at a distance of 150,000,000 light-years from the earth. Even this "super-galaxy"—so named by Professor Harlow Shapley, Director of the Harvard College Observatory—is of small importance when compared with that small part of the universe that we can see from the earth. In whatever direc-



American Museum of Natural History

Fig. 11. Johann Hevelius, a seventeenth-century German astronomer, with a quadrant by means of which he measured the altitudes of heavenly bodies

tion we point our telescopes we find other similar "specks"—millions of them scattered throughout space. Can it be, asks Professor Shapley, that all these widely separated objects are themselves obedient members of a single family, reflecting the universality of gravitational law, and at the same time hinting at incomprehensible intervals of time? Do they oscillate like gigantic pendulums, in periods that run into thousands of millions of centuries? To both these questions Professor Shapley answers: "Yes!"

HUBBLE'S DISCOVERIES

It was in 1934 that Professor Shapley expressed these views before the

Royal Astronomical Society, when present in London to receive the Society's Gold Medal. Since then Dr. Hubble has announced that he calculates the boundaries of the metagalaxy—the universe beyond our own—to be not less than 6,000 million light-years in diameter, and estimates that it contains 500 million million galaxies!

This is what the 100-in. Hooker telescope has taught us. What further mysteries and marvels will the new Palomar 200-in. telescope reveal, with its mirror having four times the light-gathering power of the 100-in. and capable of penetrating more than twice as far into space? It will open up for investigation an unexplored sphere of thirty times the volume of that hitherto known and, it is estimated, will render visible at least ten times as many stars as are visible at present. It may give us the answer to the supreme mystery of the heavens—do the stars go on and on—does space go on and on—or does space end, and if so, what is beyond the end? Einstein maintains that space and everything in it is curved, and that in the same way that we travel round the earth and come back to where we started from, so is it with the universe—by which term we include the “other universes” such as the Andromeda Nebula. Some astronomers believe that the 200-in. telescope may enable us to determine whether Einstein is right. But in the past we have held similar hopes. Bigger and bigger telescopes have been constructed and have shown—what? Simply, more and more stars. The hope that because we have now constructed a super telescope we shall solve this supreme mystery is one that may not be fulfilled. There are those

who see no reason why the extra 100 inches should do more than the extra 60 inches did when the Mount Wilson telescope was constructed and hailed as the “largest yet.”

HOW MUCH DO WE KNOW

Let us conclude this section with a very brief summary of the steps that have led to our present knowledge of the universe. From the conclusions arrived at we shall gain some idea of the enormous strides that have been made by science in the comparatively short period of a century, for it is only about a century since the actual distance of a star was for the first time ascertained (in 1838) by F. W. Bessel. The next step was the discovery that the stars are moving in space like flocks of birds—“flocks” that, as we have explained, have nothing whatever to do with the grouping of the constellations, for these are but man-made starry pictures. In 1904 J. C. Kapteyn, a Dutch astronomer, discovered that there are two main streams of movement, the stars of which are moving in different directions. In 1918, Herschel's suggestion that our sun belongs to the Milky Way and that this and all the stars we know make up one great star cluster, received confirmation when Professor Shapley showed that the 93 known globular star clusters are a kind of skeleton or framework for the Milky Way. They form a vast system of about 100,000 light-years diameter, with its center some 30,000 light-years distant from the sun.

Professor Shapley does not think that the universe ends even at the boundaries of this enormous system. In 1923 he found that one at least of the spiral nebulae is situated beyond—and not in—the Milky Way,

and its distance has now been placed at 680,000 light-years. In 1920 Hubble, using the 100-in. Mount Wilson reflector, concluded that all the spiral nebulae—the estimated number of which he placed at 2,000,000—could be nothing less than external galaxies. He suggested that each one is more

or less a replica of our Milky Way but situated at a distance so remote that light from some of them requires as much as 500,000,000 light-years to reach us.

And having carried my readers so far, it will be best to leave them there—alone with their thoughts!



"Old Faithful," the famous geyser in Yellowstone Park, has regularly spouted for four minutes every 60-80 minutes to a height of 150 feet. Details of its working are shown on page 111

SECTION II

OUR HOME, THE EARTH

CHAPTER 6—HOW THE EARTH BEGAN

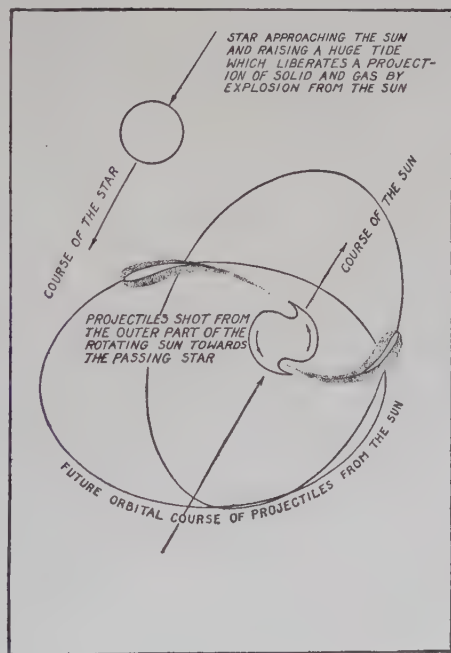
HOW did the earth begin? This is a question almost as old as man's curiosity. Even today, when so many of the puzzles of ancient times have answers which seem simple to us, the origin of the earth is still one of the unsolved mysteries of science.

Like all scientific problems, this problem for its solution must be checked against the body of known facts, and tried out in the light of all pertinent scientific contributions. The fund of human knowledge has been advancing so rapidly during the last century that many theories universally acceptable once upon a time are nowadays in the discard. This applies particularly to theories about the origin of the earth.

Nearly 150 years ago the celebrated French philosopher, Laplace, advanced a theory that was accepted by most scientists during the nineteenth century. He suggested that the earth, and indeed the whole solar system, had evolved from a cloud of gas of enormous proportions, such as our telescopes show us are scattered by the thousands throughout the heavens. According to his theory this gaseous cloud, or nebula, contracted and condensed, and in so doing left behind it, at irregular intervals, huge masses that subsequently formed the planets of the solar system to which the earth belongs (Fig. 2). The sun he thought to be the nucleus of this great nebula, and suggested that it was still contracting steadily.

Subsequent research tended to show that Laplace's "nebular hypothesis" could not be the final solution of the mystery, for many serious objections to it were advanced in the light of later discoveries.

However, many significant facts seemed to be in accordance with Laplace's theory; for instance, all the planets rotate on their axes in the same direction, that in which the sun itself rotates; moreover, they all re-



Popular Science Magazine

Fig. 1. Diagram illustrating the planetesimal hypothesis of the formation of the earth. See the text for an explanation.

volve about the sun in the same direction. Furthermore, all their satellites revolve also in the same direction—with one or two exceptions that are really of minor importance, since their divergence from the general rule can be accounted for satisfactorily.

LAPLACE'S THEORY

There are several facts that cannot be explained by, or reconciled with, Laplace's hypothesis, although many attempts have been made to fit the pieces of the jigsaw puzzle into their places. The final argument against the theory has been advanced by the mathematicians, who are convinced that on the mathematical side alone the difficulties are insuperable.

Chief of these difficulties is the fact that if contraction were to occur as suggested by Laplace it must occur on a far greater scale than he imagined. In other words, the result of contraction would be not a series of planets but a star. We are still left wondering how and why the planets originated.

Without probing too deeply into complex scientific reasons, it can be said that, while Laplace's theory is adequate to account for the birth of a star—such as our own sun—and indeed is generally accepted as sufficient explanation of how stellar groups or island universes (as they are called) arose, it is inadequate as an explanation of how a planetary system might arise. In other words, it does not explain why such comparatively small bodies as planets and their satellites ever appeared in the universe.

PLANETESIMAL HYPOTHESIS

In recent years a remarkable theory has found increasing support

among scientists. It is now supposed that the solar system as we know it is the result of a very rare astronomical accident. So vast is interstellar space, however, that there may be myriads of suns in the universe each possessing its own satellites. But it may be equally true that our sun is the only star in the heavens that has a number of planets.

The theory supposes that, in some incredibly remote epoch of time, an epoch when our familiar sun was a larger and more magnificent star, another star approached it. Inevitably the enormous gravitational force exercised by this star tended to raise vast tides on the sun. The sun, however, being a body of enormous mass and strength, exerted a similar influence on the passing star. Supposing the two bodies to have approached too closely, they each must have been blown to pieces under the releasing influence of the tidal or gravitational pull of the other and their own enormously explosive interiors. Two great American scientists, Chamberlin, the geologist, and Moulton, the mathematician and astronomer, co-operated to work out a new theory of the explosive derivation of planetary nuclei of solid and other matter as result of the disruptive approach of a star. They concluded that the probability is that the sun exploded spasmodically in the direction of the tidal pull due to the passing star. This would involve a double explosion, one towards and one away from the star, thus shooting out pairs of projectiles in opposite directions. Each projectile would follow a curving course due to the explosion in combination with the rotation of the sun itself. Consequently each sun-bolt thus expelled would follow a course first away from

the sun, and then back again to the sun as result of gravity, resulting in an elliptical orbit.

It is supposed that a series of five explosions tore the sun, shooting out great bolts of its material. Chamberlin and Moulton postulate that much of this material was solid, and that these solid particles gathered together in the course of their orbital paths into our present planets. From the idea that much of the planetary substance was expelled solid from the sun, and remained solid during the process of planet growth, the individual pieces were called planetesimals, or little planets, by Chamberlin. From his point of view we conclude that some of the planets, including the earth, were never in a molten, much less a gaseous state. One modification of this theory requires the solid masses to have fallen together so hard and fast that the growing planets were all liquefied by the heat and some were made gaseous in whole or in part, as they remain today. The satellites also are quite simply and logically explained by the planetesimal theory.

TIDAL DISRUPTION THEORY

Two British scientists, Jeans and Jeffries, have supported a related and perhaps resultant theory. They

assume only tidal pull without explosive action on the part of the sun for the origin of the planets. They suggest that the tidal pull on the smaller of the two stars was so great that the sun tides grew higher and higher, sweeping round the sun as it rotated on its own axis, until they became mountainous in size, and finally streamed off into space towards the passing star. The tidal pull, however, did not strip the sun material beyond the sun's gravitational control, but left it to revolve around the sun as a huge cigar-shaped cone of dispersed materials. These materials gradually condensed into knots of matter, from which further conden-



Fig. 2. A solar system in the making? The spiral Nebula in Ursa Major, the Great Bear

sation and gravity packing produced our planets.

Following this line of argument one finds it relatively consistent that the planets should be as they actually are, and that the satellites of the planets should be where they are, and rotate and revolve as they do. In these theories of the origin of the earth we see the marvelous ingenuity of man, constructing new and better theories to keep pace with the march of knowledge. At the present time the field appears to be wide open, with at least two highly developed theories, entirely distinct in certain essential respects, though each competent to explain almost all the main facts of our solar system. The very fact that we have two such theories to choose from suggests that there are others in the making. All that can be said at present is that we have left behind certain theories which we feel certain cannot be adequate, and we believe that those now before us are considerably closer to the truth.

On the question of the age of the earth there has probably been as much discussion as on the question of the earth's origin. In the seventeenth century it was suggested by Archbishop Usher, who was the first to attempt to formulate a biblical chronology, that the creation of the world took place in 4004 B.C. Such a date is impossible, as is at once evident from the fact that at the date mentioned, civilization had existed in Egypt for many centuries. If six noughts were added to Usher's figure it would then be more in keeping with modern estimates—for any such figures can be only estimates.

To help in solving the mystery of the age of the earth we rely on the teachings of astronomy, geology, and

physics. Let us see what each of these sciences can tell us.

Lord Kelvin, in 1862, computed the time required for the earth to cool from a temperature of 3000° C. to its present temperature, supposing the recognized laws of heat radiation to have prevailed unchanged in principle during that time. The mathematical answer to the problem came out as 30,000,000 years. Lord Kelvin did not claim that figure was the age of the earth, but if the earth had been cooling in that manner it would require so many years. About forty years later the implications of radium as a possible source of heat became recognized, and, of course, Lord Kelvin's fundamental premise could not be even considered. The mathematics of the problem are still acceptable, but the conclusions have no applications to the age of the earth.

GEOLOGICAL MEASUREMENT

In any case, geologists had never been satisfied with these figures, the period being too short in their opinion to allow of the formation of some of the rocks in the earth's crust. From measurements of these rocks, W. Phillips (1775-1828) estimated that originally the deposits must have been at least 300,000 feet thick. By comparing the rate at which similar rocks are being formed today—a thickness of a foot in a century—he came to the conclusion that the earth's age must be at least 40,000,000 years. Another geologist, Sir Archibald Geikie, using a similar basis, revised the estimate, in 1899, to 100,000,000 years. Poulton, in 1896, working from the biological angle, suggested 500,000,000 years as the time necessary for the development of animal and vegetable life to their present stages of evolution.

The problem was attacked by Solas in 1909. He took as his basis the saltiness of sea water, the degree of which is constantly increasing, as every year more salt is carried into the sea by rivers. He estimated that 150,000,000 years would be required for sea water to have reached its present degree of salinity.

The most recent estimates have been made by the physicists, who were greatly helped in this direction by the study of radioactivity—a line of research that was, of course, unknown to Lord Kelvin.

Investigation has shown that radium is disintegrating, and that it gradually changes into another substance. In a period of about 1,600 years a portion of radium will have changed so that only half the original portion will be radium, the remainder being a debris that does not possess the properties of radium. Then the remaining half will similarly have a period of equal length before it has half disintegrated, and so on. Finally the last fraction of the last half is so small that it is imperceptible. A product of radium decay which remains free of further changes is helium. The amount of helium in the debris, provided it all resulted from radium disintegration, indicates the original quantity of radium. The ratio between the original amount of radium and the quantity remaining still unchanged yields the time during which that particular radium concentration has been undergoing change. By careful measurement, therefore, it becomes possible to determine the age of such a mixture of radium.

WHAT URANIUM TELLS US

Other substances of the radioactive series behave similarly, but the time

required for each to deteriorate into half-values varies. One such substance, uranium, changes into debris that ultimately becomes a special kind of lead. The change from uranium into lead takes place at an absolutely uniform rate. No extremes of heat or of pressure affect in the slightest the rate of change. This rate has been very accurately measured in the laboratory. Physicists are able to say—from the fact that in no case is the uranium as found in various rocks less than its accompanying debris—that uranium cannot have been in those rocks for as long a period as 4,500,000,000 years. Careful measurements of the amount of uranium and the amount of debris suggests that the uranium has been present in the rocks for some 1,500,000,000 years. A similar period is arrived at from the examination of thorium, another radioactive substance.

It has been discovered that at Morogoro, in East Africa, there is a deposit of pitchblende which contains a proportion of lead of the special type that is the final product of the radioactive changes undergone by uranium. Experiment has shown that the time required to produce the proportion of lead present in these Morogoro deposits is 700,000,000 years, assuming that the parent uranium was originally pure. Of other minerals examined in this way the oldest in North America comes from Keystone, South Dakota. This mineral is 1,460,000,000 years old. A still older mineral from the Karelian Peninsula between Russia and Finland is 1,850,000,000 years old.

If we assume that the earth solidified some 2,000,000,000 years ago, we must add considerably to this figure to allow for the cooling. Some guide

as to what the final figure is likely to be may be obtained from Professor E. R. Rutherford's researches into the relative abundance of uranium and resultant substances, for he found that the greatest possible age for the crust of the earth is 3,400,000,000 years. It is safe to say that the earth is between 2,000,000,000 and 4,000,000,000 years old.

Taking as a provisional figure 2,000,000,000 years, let us endeavor

to see what it represents. It is more than 100,000 times the length of human history, and more than 1,000,000 times the length of the Christian Era. In this book there are about 280,000 words. If we take as an average six letters to a word, we have a total of approximately 1,680,000 letters. The length of human history would be represented by the last word in the book, and the period since the birth of Christ by less than the last letter!



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Fig. 3. The miner drilling for pitchblende looks about like any other miner. He needs no special protection from the radium which is well buried.

The whole of the remainder of the book represents the time that passed before man appeared on the earth. It is an interesting thought to remember that the earth existed for thousands of millions of years before man came; that it will probably exist for thousands of millions of years after man has vanished; and that the whole of the period of life on the earth is but a brief span between these two periods of the earth's existence.

FIXING A DATUM LINE

To many, however, the fact that estimates of the age of the earth have been increased by two hundred times in sixty years, will suggest that the last word has by no means been said, and that we must wait for further evidence before we accept even the most recent estimate. And we may profitably pause to ask ourselves if we should not consider more closely exactly what we mean by these millions of years we speak about so glibly. It is desirable that we should fix some kind of a "datum line" in regard to what we call time. On the one hand we have the "dance of the electrons" in which these inconceivably minute particles rotate around their parent atomic nucleus a million billion times in one of our seconds. On the other hand, perusing the tables compiled by Professor Eddington of the astronomical periods required for the life of a star, we find that the duration of one stage alone requires twenty trillion years! Somewhere between the two extremes is the mystery of the age of the earth.

THE EARTH IS NOT FLAT

Several things show that the earth's surface is not flat. There is the well-known fact that a ship gradually dis-

appears over the horizon, whether it steams north, south, east, or west; and that as its distance increases, first the hull, then the deck, funnels, and masts, sink below the horizon (Fig. 4). Even a small telescope will show the topmasts when the ship is "hull down." If the earth were flat the whole ship would fade away gradually as the distance increased. Sometimes this illustration is incorrectly advanced to prove that the earth is a globe. It does not prove this, of course, but only that the earth's surface is curved. Conversely, when approaching land, the lookout in the crow's nest first sees the highest peaks of a mountain range, and as the ship draws nearer to the land, more and more of the mountains become visible (Fig. 4).

An astronomical proof that the earth cannot be a flat plain is afforded by the fact that the sun does not rise at the same instant in every country. It does not rise in the United States until some six hours after it has risen in Britain, and at the same time it is setting in India and Central Asia (Fig. 4).

THE EARTH A SPHERE

The curvature of the earth can actually be seen in photographs made with the very long, infrared rays of light. By means of films made sensitive to infrared rays, which are able to penetrate haze and fog so that distant objects can be "seen" by the camera, photographs have been taken from an airplane of a far-distant horizon from such a height that the curvature of the earth is distinctly apparent (Fig. 6).

Actually the amount of curvature is comparatively small, being only eight inches to the mile. That is to



Fig. 4. Various methods of proving conclusively that the earth is not flat

say, could we obtain a level girder a mile in length and suspend it over the sea on a calm day with the middle just touching the surface of the water, each end of the girder would be four inches above the water (Fig. 4).

Proof that the earth is a sphere can be given in several ways, as for instance by the fact that if we travel continually in the same direction we return eventually to our starting point. Astronomically there are several proofs, as for example in an eclipse of the moon, which anyone may see perhaps once or twice a year. When this occurs the moon passes through the great shadow cast by the earth in space, and as we watch the earth's shadow creeping over the surface of the moon, we see that the edge is circular in outline (Fig 4). Only a globe will throw a shadow that is circular under all conditions. The ancients knew that a lunar eclipse is caused by the moon passing through the earth's shadow, and Manilius and Cleomedes, two astronomers who lived some 2,000 years ago, advanced this as a proof that the earth is spherical.

Although the earth is a sphere, it is not a perfect sphere, for it is slightly flattened at the poles—or to put it in another way, it bulges slightly at the equator. To say that the earth is flattened like an orange is not altogether correct, for the equatorial diameter is only 26 miles greater than the polar diameter (Fig. 5). As this represents a difference of only about one part in 304, a similar amount of flattening

in an orange would not be noticeable to the casual observer.

The reason for this bulging at the earth's equator is that it is rotating on its axis at a comparatively high speed. Every particle of matter of which the earth is composed is subjected to centrifugal force—the tendency of bodies to be forced perpendicularly away from the axis of rotation. In the case of the earth this force is really very considerable and the

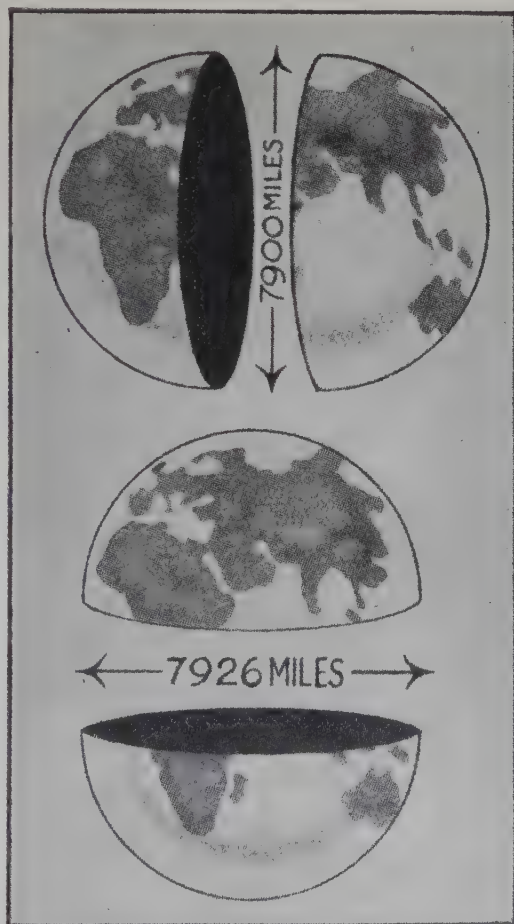


Fig. 5. The difference between the Polar diameter (top) and the Equatorial diameter (bottom) of the earth

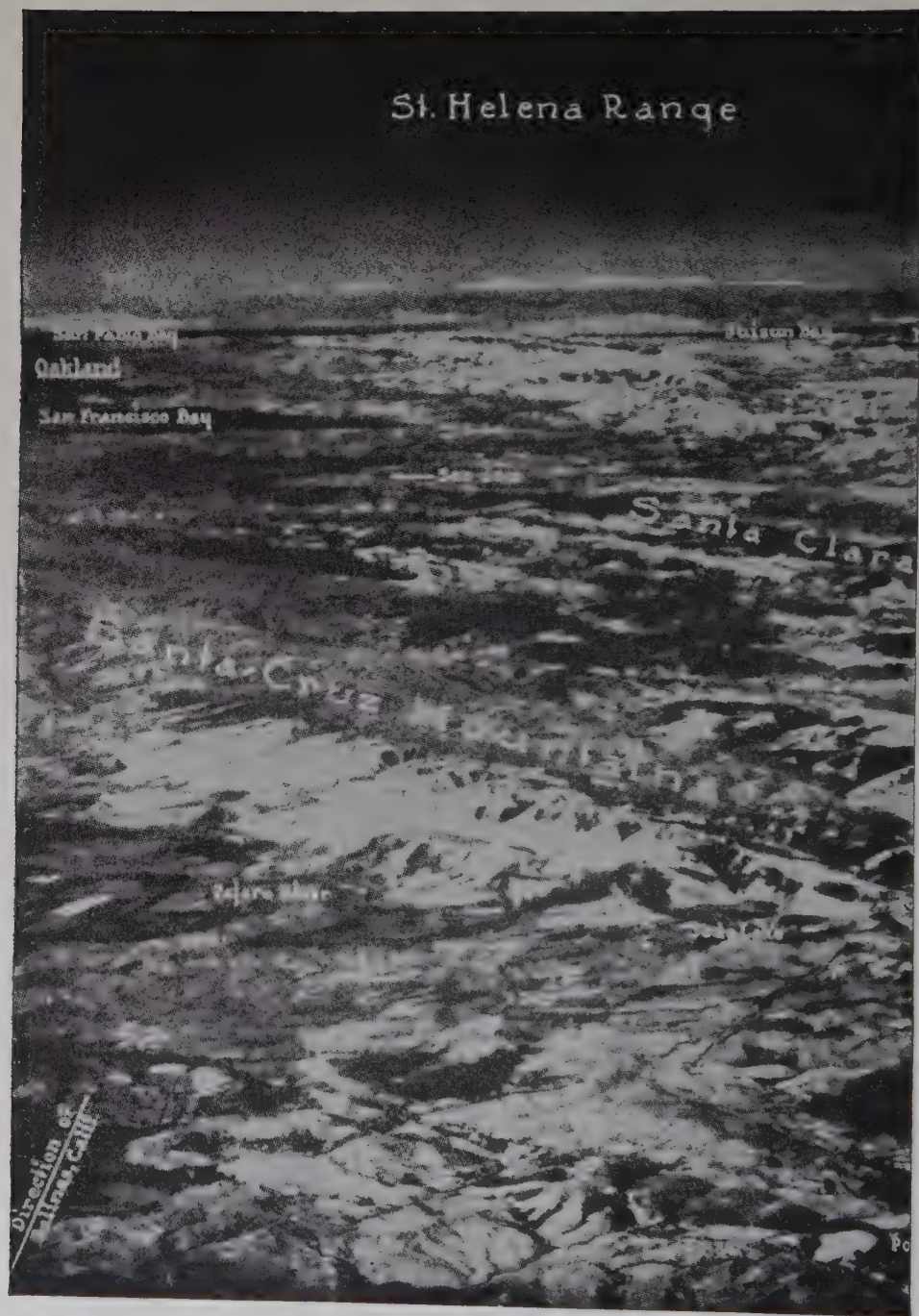
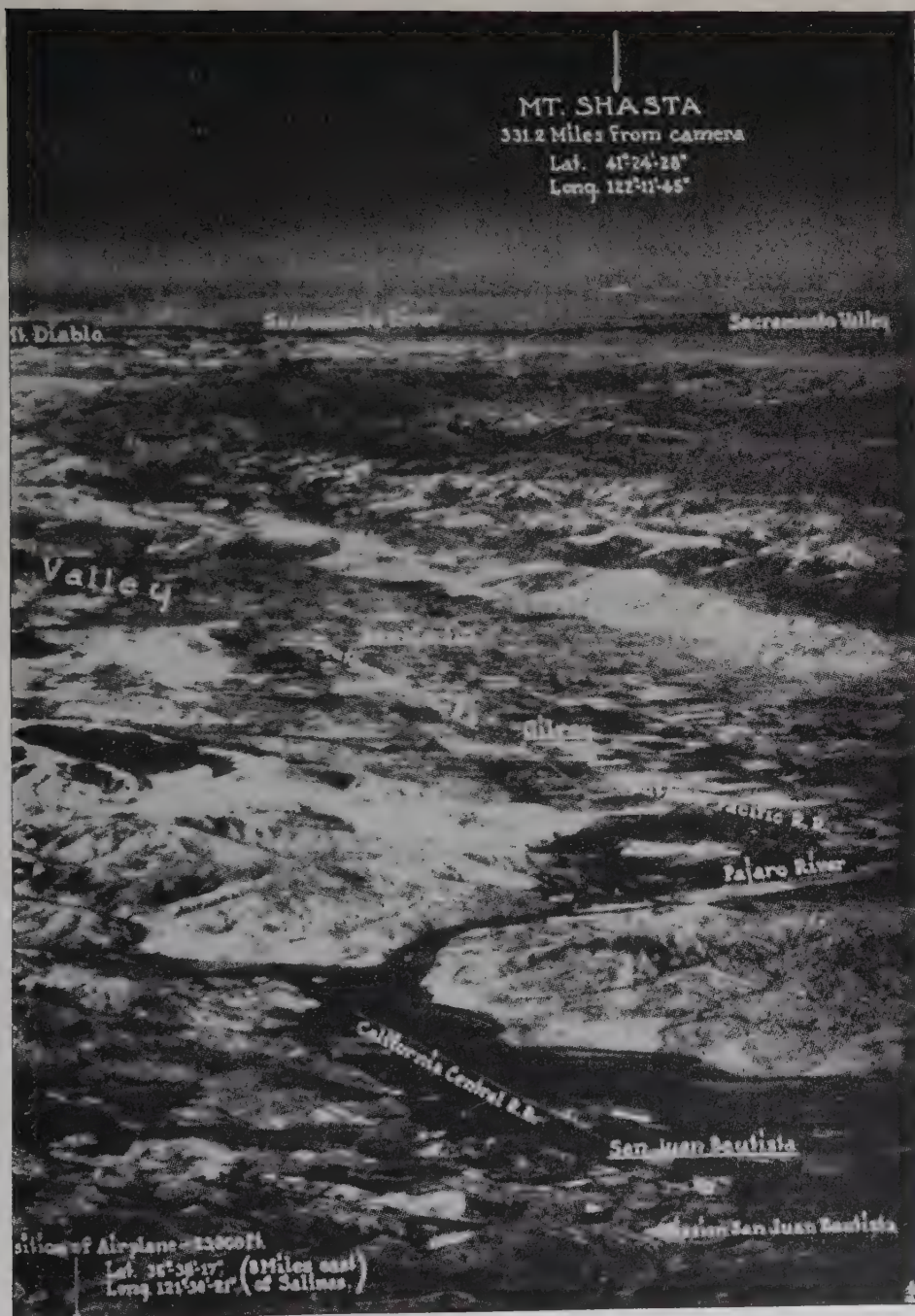


Fig. 6. This astonishing infrared photograph, taken from a height of $4\frac{1}{2}$ miles, covers an area of western America with a radius of over 331 miles. The curvature



of the earth can be seen on the horizon. Infrared photography has made such pictures possible, since it can penetrate haze and mist.

equatorial bulge is negligible only because of the great strength and rigidity of the earth's interior. However, some of the other planets are rotating at greater speed, and are more largely of gaseous composition, and in their case the equatorial bulge is obvious at a glance, particularly in the case of Jupiter.

EFFECT OF GRAVITY

So long as the effect of gravity is sufficient to counteract centrifugal force, there is no likelihood of our being thrown off the earth into space. As the earth's rotation carries objects at the equator through a distance of 24,902 miles in 24 hours, we can see that their speed is approximately 1,000 miles an hour. If the earth were to be "speeded up" suddenly to seventeen times its present speed, so that it completed a rotation in 85 minutes, everything at the equator would rise into the air and disappear into space! Fortunately, the pull of the earth's gravity is more than sufficient to counterbalance centrifugal force and people at the equator need have no fear that they will be thrown off the earth—since nothing is likely to increase the speed of the earth's rotation.

Rather should they congratulate themselves, for at the equator a man can jump a given height with less physical effort than is required at any other place on the earth. This is because the pull of gravity is modified to a certain extent by the speed of 1,000 miles an hour at which the earth's surface at that point is traveling. Other things being equal, it should be easier, therefore, to put up records for the high jump at the equator than in other latitudes. Actually, however, the advantage is

merely an academic concept, not appreciable to an athlete. The long radius of rotation at the equator counteracts the effects of the surface speed. Furthermore, at the equator the centrifugal force is directly opposed by gravity, whereas at other latitudes the application of gravity is inclined to the direction of centrifugal force. The outcome of these balancing conditions is to nullify any supposed advantage that high jumpers might have at the equator.

Gravity is the great force that not only keeps us on the earth, but keeps the earth from flying off into space. Its effects are apparent everywhere and it is one of the most important forces in nature. Without it the universe would "go to pieces." The "laws" of gravitation were discovered by Sir Isaac Newton. According to the story, his attention was directed to the matter by a falling apple.

LAWS OF GRAVITATION

There are two chief laws of gravitation. The first is that the force of gravity varies directly in ratio to the mass or quantity of matter. This means, that if a mass is doubled, its attraction is doubled; if the mass is trebled, the attraction is trebled, and so on. The second law is that the force of gravity varies inversely to the square of the distance between the bodies. This simply means that if the distance between the two bodies is doubled, the attraction is reduced to a quarter, if the distance is trebled, it is only one-ninth as great, and so on.

Some curious effects result from these "laws." As the earth is some 26 miles greater in equatorial diameter than in polar diameter, anyone at the equator is some 13 miles further from

the center of the earth than when at the poles. Consequently, a person will weigh less in Africa than he will in Greenland, because of the second law of gravity, already mentioned. Similarly, a person weighing 150 pounds on the earth would weigh only 24 pounds on the moon, and physical effort would be reduced correspondingly. If we can jump five feet here, we could—with the same expenditure of physical energy—jump 30 feet on the moon. It would be as easy to jump over a lunar house as it is to spring over a low fence. We could pick up an automobile there as easily as we pick up a bicycle here.

The foregoing suppositions are easily reduced to harmless absurdity by remembering that any athlete would be completely breathless on the moon because there is not enough mass in the moon to collect and hold an atmosphere.

Such comparisons are interesting in a way, but we should always realize that suppositions contrary to the known facts are more deceptive than other kinds of hypothetical cases because they are based on a fallacy.

GALILEO'S FAMOUS EXPERIMENT

Galileo's famous experiment from the Leaning Tower of Pisa seemed to show that all bodies fall to the ground at the same speed. Actually, a ball of lead and a ball of wood will fall to earth at equal speed *in vacuo*, if they are of identical diameter and if their surfaces are of equal smoothness. Even if the ball of lead weighs 56 pounds and the wood one-twentieth of an ounce, the two would fall at the same speed if the friction caused by the air did not differ. When bodies are moving at high speeds, of course, the frictional forces are considerable

and must always be taken into account.

It is due to the proportional differences in frictional surface area that a man dropping down a mine shaft is killed by the fall, a cat making the same drop is bruised but not seriously hurt, and a mouse after such a fall jumps up and runs off unharmed.

A feather and a penny dropped from the same height will not reach the ground together in ordinary circumstances, because the feather is buoyed up by the air, the resistance of which hinders the motion of falling. If the feather and the penny were dropped in a vacuum, however, they would both reach the ground at the same instant. In other words, all bodies will fall to earth at the same speed except in so far as they are subjected to interference by the air.

The speed at which bodies fall is not a constant one, for a continually acting force, such as gravity, will move a body at an ever increasing speed. This is known as a uniformly accelerated motion. That is to say, a falling body gains speed as it falls, although resisted by friction. For example, a body falling from a height of 1,600 feet will fall 16 feet in one second; 64 feet in two seconds; 144 feet in three seconds; and so on, as shown in Fig. 7. Its velocity at the end of the first second will be 32 feet per second; at the end of the second, 64 feet; at the end of the third, 96 feet. This is diagramed in Fig. 7. Such a body will reach the ground from a height of 1,600 feet in 10 seconds, and at the time it touches the ground it will be traveling at a velocity of 320 feet per second. High explosive bombs dropped from a height of 12,000 feet will be traveling at over 700 miles an hour by the time they

reach the ground—nine times as fast as a streamlined train!

WHAT GRAVITY MEANS

Gravity holds the earth in its orbit, the sun preventing it from flying off into space. The arrangement may be likened to a boy swinging around his head a weight fastened to the end of a rope. So long as the rope is there, the weight is held in its path, but should the rope break, the weight would fly off to a considerable distance. The sun is a much mightier body than the earth and exercises a tremendous pull. It has been calculated that this invisible force is so strong that if a material connection were needed to replace it, this could only be obtained by covering the whole earth with steel wires set as closely together as blades of grass in a field! Incidentally, it may be mentioned that as the sun is possibly parting with its substance, and as its mass would, therefore, be diminished, its gravitational hold on the earth may be growing less. In other words, the earth's orbit may be correspondingly growing, to an extent that would increase the distance between the sun and the earth at the rate of a yard in a century. This may seem to be an insignificant amount, but in a trillion years it

would produce far-reaching consequences.

It is interesting to know that despite the flattening of the polar diameter being so comparatively slight, it can be detected by the swinging of a pendulum. A pendulum swings, of course, because it is attracted by the mass of the earth beneath it. Thus if the earth were a perfect sphere its attraction would be identical at all places and a pendulum would swing with exactly the same beat at all places on the earth. In fact, however, the oscillations of a pendulum vary according to the place where the pendulum is situated. These oscillations are more rapid at the poles than at the equator, and would result in a pendulum clock that keeps time at the equator gaining three and one-half minutes in a day if taken to the poles. This is because the degree of the earth's attraction on the pendulum depends on its distance from the earth's center.

FOUCAULT'S DISCOVERY

A pendulum will also prove to us that the earth rotates on its axis, as was first shown in 1851 by J. B. Léon Foucault (1819–68). He suspended an iron ball by a wire 200 feet in length, from the dome of the Pantheon in Paris. The ball was allowed to swing and at

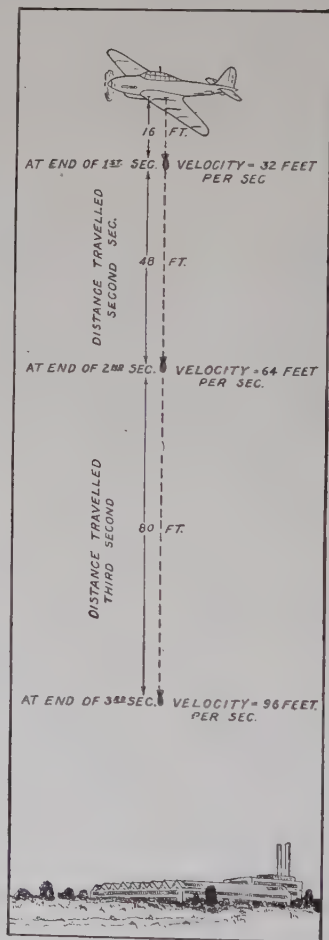
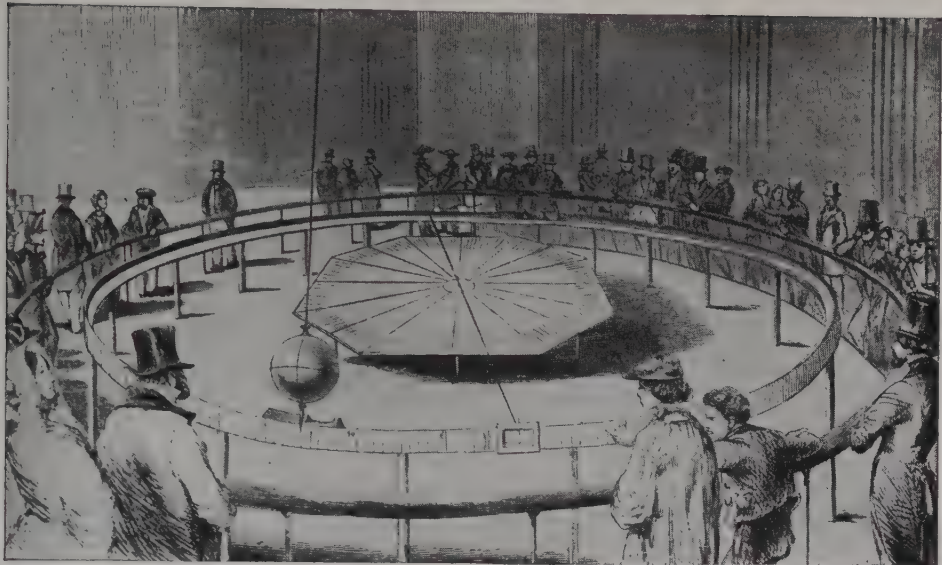


Fig. 7. Speed and acceleration of a falling body



Black Star from the Bettmann Archive

Fig. 8. To prove the rotation of the earth, Foucault's famous pendulum was suspended on a wire 200 feet long from the dome of the Pantheon, in Paris, in 1851

each oscillation it touched a tray of sand, thus leaving a mark on the tray every eight seconds. After a few moments it could be seen that the direction of the pendulum's movement was changing, for the ball marked the sand in a new place (Fig. 8). Soon it appeared from the marks that the whole of the Pantheon was rotating in an anti-clockwise direction below the swinging pendulum—which, in fact, was exactly what was happening, for the rotation of the earth had carried it through part of a circle while the pendulum was swinging.

If hanging at either the North or South Poles, a pendulum would indicate that the earth had turned a complete circle beneath it in 24 hours, or to be more exact, 23 hours 56 minutes 4.1 seconds, the length of what is called the sidereal day—that is, the period of rotation of the earth. The movement would be clockwise at

the North Pole and anti-clockwise at the South Pole. At the equator the pendulum would show no rotation.

The shift of the course of the pendulum is not immediately clear. Consider a swinging ball started in a direction true north. While it is swinging, the point it left travels farther than the point to which it was aimed. Even though the points are actually only a few yards apart there is a real difference in their linear velocities. The point nearest the equator goes the faster. In that little time required for the swing, the line between the two moving points is no longer the line of the swinging ball. The ball just misses the point at which it was aimed, grazing it on the left of the moving ball. On the return swing the original point will go farther than the northern point, and the ball will come to the end of its swing just too late to cover the point, which now

will be off to the left of the ball. In each case the ball appears to miss its object by passing to the right.

When swinging straight east, the points of departure and arrival are both on the same line of latitude, and one might expect that there would be no deflection. However, except at the equator, gravity is inclined to centrifugal force which would cause a crowding towards the equator except for the balance between gravity, radius of rotation, rotation, and linear velocity. When the ball swings to the east, the velocity of swing is added to the centrifugal force of the rotating earth, and the ball appears to edge over towards the equatorial side. When the ball swings west, its velocity is subtracted from that of the moving earth beneath it, the total centrifugal force on the ball is reduced thereby, and the ball appears to drift sideways in its swing away from the equatorial side. In either case the ball appears to swing off to the right of its course, just the same as it did when swinging north or south. This explains why we say a moving body in the northern hemisphere tends to be deflected to the right and in the southern hemisphere to the left of another moving body.

EFFECTS OF ROTATION

The rotation of the earth has to be taken into account in several ways in daily life. In long-range artillery work, for instance, allowance must be made for the fact that a shell fired to the north or south appears to deviate to the right of a man facing in the direction of fire. This is because the earth is rotating beneath the shell as it rotates beneath the free-swinging pendulum. A practical application of the earth's rotation is seen in the gyro-

compass, which would not work at all if the earth did not rotate on its axis.

The gyro-compass, or "Iron Mike," as it is often called on board ship, is among the most interesting of the devices with which science has endowed the navigator. The slightest deviation of the ship's head from its course is immediately and automatically corrected by this steering device. With the aid of the gyro-compass one man can steer a large ship: a task which without it would command the attention of half a dozen men.

About the middle of the eighteenth century a man named Serson conceived the idea of applying the gyro principle to the compass, but lost his life at sea while carrying out experiments. The first practical gyro-compass was put into operation in 1911. During World War I it was used in warships and submarines, and immediately after the conflict it was adopted first by American commercial craft and then by the mercantile marines of other nations.

THE CRUST OF THE EARTH

We live on the very superficial outside of the earth. Nobody can see through even a foot of rock, and what there is beneath the surface we know very little about by direct observation. However, the main calling of the geologist is to know and to use what he knows about the interior of the earth's crust. The scientist's method of examining the earth's interior involves very little direct observation, but a great deal of inductive reasoning from data which can be accumulated at the surface of the earth. The deepest oil well ever made went 15,004 feet down into the earth, but

even this is a mere pinprick compared with the 4,000 miles to the earth's center. Even if we add the height of the highest mountain (five and one-half miles) to the depth of the deepest ocean (about six miles) making, say 12 miles, we get only a minute fraction of the total radius of the earth. It is clear, therefore, that we can learn little or nothing from actual observation of the conditions of the earth's interior and that for our knowledge we must rely on other methods.

The average density of the rocks of the earth's crust has been found to be from two and one-half to three times that of water. Similarly, careful measurement shows that the density of the earth as a whole is about five and one-half times that of water. From this it follows that the density of the earth must be considerably greater near its center than near the surface. We are thus led to the conclusion that the earth's interior has a larger proportion of dense substances than has the surface.

Density increases with pressure, and as the pressure at a depth of 100 miles amounts to over 300 tons to the square inch, we might be justified in assuming that at great depths the enormous pressure is the cause of the increase in density. This theory, at one time held fairly generally, has now been discarded, however, in view of certain serious objections. Instead, it is generally believed that the high specific gravity of the earth's interior is due to its being largely composed of heavy metals, probably iron, or iron and nickel.

COMPOSITION OF THE EARTH

From the evidence of the transmission of earthquake shocks it is clear that there are breaks in the composi-

tion of the earth's interior at depths of about 35 miles, about 1,000 miles, and about 2,000 miles. (The velocity of earthquake waves depends upon the compressibility of the transmitting media; the compressibility of various rocks being known, it is possible to postulate the kinds of rocks which might cause the known earthquake wave velocity.)

A composition of the earth has been suggested by the late H. S. Washington, of the Geophysical Laboratory, Washington, D. C., which meets the requirements both as to the total density of the earth and the compressibility properties demanded by the behavior of earthquake waves. The outermost crust, about 35 miles thick, has a composition about equal to that of a lightweight rock rich in silica, called granite. The next layer, about 950 miles thick, grades at the top from a rock moderately low in silica and rather heavy, basic rock (very low in silica) at the bottom. Next comes a layer about 1,000 miles thick which is a mixture of very basic rock and metallic iron, mingled in pieces of irregular size, but grading downward to a mixture of constantly increasing iron content. The innermost part of the earth, including the remaining 2,000 miles of radius, is apparently composed of iron with minor amounts of nickel.

Earthquake records are obtained by an instrument known as a seismograph—a kind of pendulum to which a recording device is fixed. A simple seismograph that will give interesting records can be made without difficulty (Fig. 9). A metal bar, perhaps five feet in length, is hung by a wire against a wall running north and south, or east and west. The bar, or "boom," rests against a metal plate

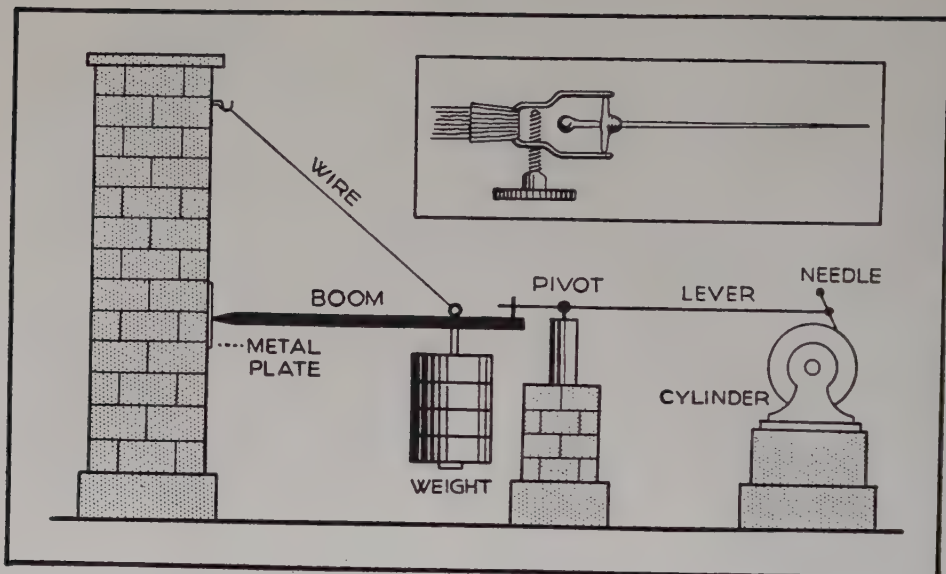


Fig. 9. How the seismograph works. Inset shows how the fine glass needle is fixed to a light extension. This needle must be free to move vertically and to rest lightly against the smoked paper on the cylinder shown with the rest of the apparatus below

to prevent it digging into the wall. Towards the opposite end of the lever hangs a heavy weight that may be a number of bricks fastened together. At the end of the lever a light extension lever—such as a long wheat straw, or piece of fine aluminum tubing—is fixed on a pivot, engaging between two uprights on the main lever, its purpose being to magnify mechanically any slight movement of the weighted lever. The record is made by a stiff bristle, or fine drawn glass thread, fixed by a spot of shellac or cement to the extension lever, and resting on a smoked paper carried on a revolving cylinder.

The weight remains in a comparative state of rest, forming a steady point, so that when the wall is moved by earthwaves, the movement is transmitted through the weighted lever and so through the magnifying lever. The movement causes the recording

bristle to move to an extent many times greater than the original movement. It scratches a zigzag line on the smoked cylinder instead of the normal line that is given when there is no earth-movement. This record is called a seismogram.

THE SENSITIVE SEISMOGRAPH

There are several forms of seismographs, but all work on the same principle. One that is now generally used, the Milne-Shaw, depends on a horizontal pendulum—a rigid metal rod supported vertically on a masonry column (Fig. 10). The boom is an aluminum rod with an arrangement at the extremity for reflecting a beam of light through suitable lenses on to a drum carrying sensitized paper. An apparatus is incorporated for “damping” the movements of the pendulum by magnets. It has the effect of bringing the boom quickly to rest after

each oscillation. The vertical pendulum, boom, and damping magnets are shown in Fig. 11. Such a seismograph is so sensitive as to show that the building in which it is housed sways like a tree in the wind. It will also show that the coastline is depressed for several miles inland with each rise in the tide. It shows, too, that a person standing on the ground makes a depression that extends for many feet around the spot.

Earthquakes may be caused by volcanic activity releasing molten matter, so causing a subsidence of the earth's crust; or by "faulting"—the slipping of rocks below the earth's surface. Subsides of the earth's crust due to volcanic processes are well known. Professor and Mrs. T. A. Jaggar have been keeping house for years on the edge of the crater of a great Hawaiian volcano. Professor Jaggar has worked out a routine inspection of certain

definite fixed points which he has established. Regularly he measures the change in vertical position of these points relative to one another, and thus determines the direction of tilt of the earth's surface. The variation in degree and direction of tilt enables him to foretell with great accuracy the future behavior of the volcano. On many of the dangerous volcanoes in Japan, the Japanese government maintains seismological stations. This is to detect the beginnings of subterranean changes which may imperil the lives and property of the whole neighborhood. In case of violent eruptions the property losses are bound to be serious, but loss of life may be prevented by wholesale evacuations. The seismograph warnings make it possible to remove the inhabitants of the area likely to be seriously affected before the eruption becomes a catastrophe.

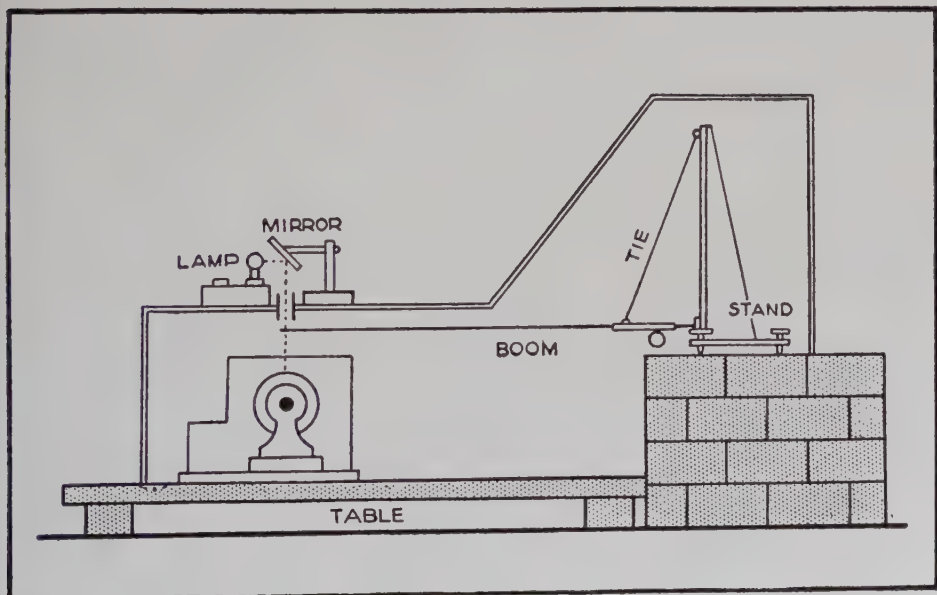


Fig. 10. The principle of the Milne-Shaw Seismograph, showing how it is operated by a horizontal boom working from a fixed column. (For explanation of working, see text)

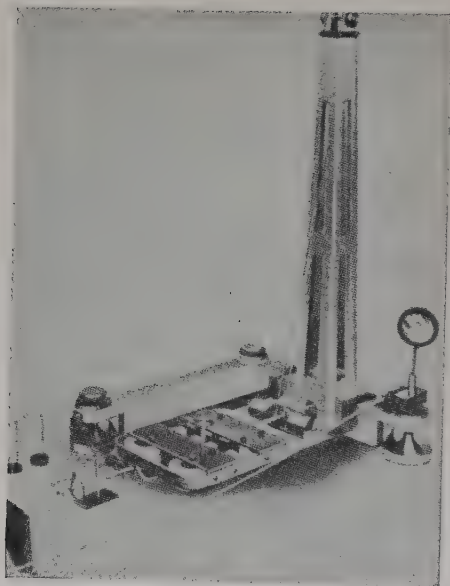


Fig. 11. The vertical pendulum of a Milne-Shaw Seismograph for recording earth tremors by a light beam falling on sensitized paper

TYPES OF EARTH WAVES

Earth waves are of three types, two of which—the primary waves and the secondary waves—travel through the interior of the earth, while those of the third type—resembling the surface waves in a pond—travel on the surface (Fig. 12). All the waves originate at what is called the focus or seismic center, and in due course they reach the recording stations where seismographs are installed. The vibrations of the primary waves are sent out in the direction of travel and these waves are therefore said to be of a longitudinal character. The secondary waves follow the same path as the primaries, but travel more slowly. As their vibrations are at right angles to the direction of travel they are known as transverse waves. Since the time required for the primary and secondary

waves to arrive varies according to the distance of the focus from the recording station, it is possible to calculate the distance of the focus by noting the difference in the time of arrival of the two waves as recorded by the seismograph. Thus the observer can tell approximately where the earthquake is taking place. An earthquake recording on a Milne-Shaw Seismograph is reproduced in Fig. 13.

Science has not succeeded in devising any method of accurately forecasting earthquakes, although evidence is accumulating that may lead to some such achievement. There are two kinds of evidence that may help in this matter. In the first place earthquakes have now been recorded for a great many years, and the statistics are carefully studied to see if the variation in their frequency is in any way related to other known terrestrial variations. The average total number of earthquakes is about 4,000 per annum, and although most of them are very feeble, one in every sixty is capable of being registered. Even in seismic countries like Italy or Japan only two earthquakes in twenty are destructive. These destructive earthquakes tend to occur in groups that may be spread over some years, and records show that they are followed by a period of comparative quiet. Thus in Japan an average period of 13 years occurs between epochs of destructive activity, and a similar kind of sequence has been noticed in other countries.

It is very difficult to explain these variations, however, and many diverse factors may enter into the matter. It is known, for example, that on the average earthquakes are more frequent in midwinter and that they vary

through the year in a way similar to the annual variation in barometric pressure. Again, a maximum frequency seems to coincide with periods when sun, moon, and earth are in line. It is improbable that any one of these details of the earth's behavior produces an earthquake by itself, but if any part of the earth is in a strained condition, increased barometric pressure or greater gravitational pull by sun and moon, may provide the "straw that breaks the camel's back."

An immediate and extremely important aid

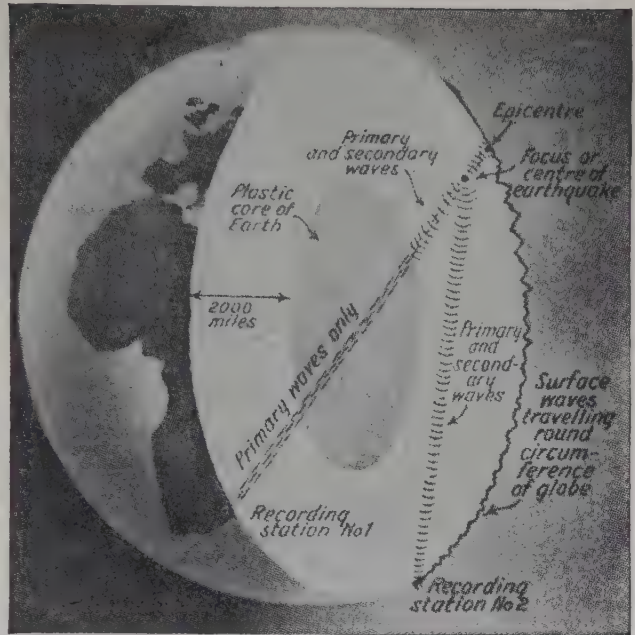
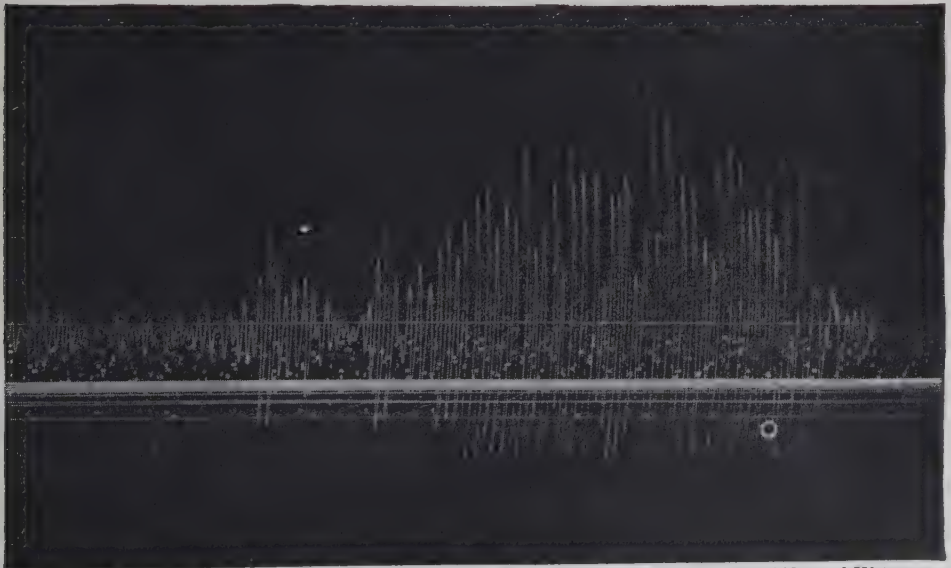
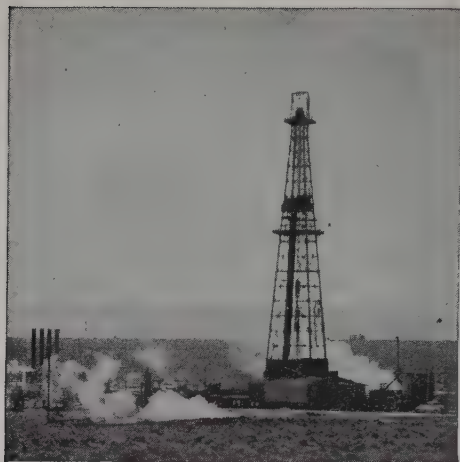


Fig. 12. Three types of waves caused by an earthquake. Only the primary waves travel through the earth's core.



American Museum of Natural History

Fig. 13. The seismograph makes a picture of the earthquake in Northern Japan, May 2, 1939



California Oil and Gas Association

Fig. 14. This oil well, drilled early in 1938 at the Wasco Oil Field, California, was sunk to a depth of 15,004 feet, the deepest hole in the world

in forecasting earth tremors lies in the observed fact that a major earthquake is preceded by a series of preliminary shocks.

DISASTROUS EARTHQUAKES

Great damage and loss of life occurs when an earthquake takes place beneath a town or city. One of the most disastrous earthquakes of recent times was that of Hawkes Bay, New Zealand, on February 3, 1931. Within 30 seconds, and without the slightest warning, the busy town of Napier was in ruins and hundreds of people were killed. Fires broke out in various places simultaneously and could not be controlled.

Ordinarily damage is distributed over a considerable area, affecting human lives and property far and wide. Early in 1940 repeated earthquakes ruined scores of villages in northeastern Turkey, causing thousands of deaths in the collapse of buildings, and in the loss of shelter and conse-

quent exposure of the people in the dead of winter. In such cases, where earthquakes are not related to active volcanoes, it would be difficult to predict earthquakes even with the help of seismographs.

Much could be written of other disastrous earthquakes but limitations of space forbid. Let us see, instead, what the seismograph can tell us about the earth's interior. We find that when the distance between the origin of the earthquake and the recording station is so great that the path of waves extends to a depth of 2,000 miles, the secondary waves do not reach the recording station. This is accounted for by the fact that although the primary, or longitudinal, waves will pass through homogeneous, liquid, plastic, or malleable material, the secondary, or transverse, waves cannot do so. Thus we infer that the interior of the earth at a depth of about 2,000 miles must be homogeneous and metallic.

BENEATH THE EARTH'S SURFACE

Whatever may be the actual condition of the earth's interior, its temperature must be comparatively high, although there is no actual evidence that it exceeds perhaps 5,000° F., a temperature that we can command in the laboratory. We know that in penetrating the earth's crust in mining, the temperature increases with the depth of the shaft, and in many deep mines it is too hot for comfort. The rise in temperature appears to vary according to the situation. By lowering special thermometers into a deep boring, made some years ago when searching for coal near Leipzig, in Germany, it was found that there was an increase of 80° F. at a depth of a mile, the temperature rising at a uniform rate of 1° F. for each 66 feet in depth.

In a boring in Kern County, California, oil was struck at a depth of about 13,000 feet and here the rise in temperature was 1° F. for every 25.5 feet of depth. Near Yellowstone Park, in Wyoming, the increase of temperature in a boring is 10° F. for every 25.5 feet of increased depth—a rise of temperature so sharp that water boils (212° F.) at a depth of only 350 feet. The hot springs and geysers of Yellowstone Park are near this locality of sharp temperature gradient, to which they are probably causally related. (View of the famous geyser, "Old Faithful," is shown in frontispiece.)

Sir Charles Parsons, the famous engineer who so successfully developed the steam turbine, suggested the sinking of a shaft to a depth of 12 miles at an estimated cost of \$100,000,000. He believed that such a shaft might

strike sufficient coal and oil to supply all requirements for millions of years, and might release untold wealth—radium, gold, silver, and diamonds, as well as new metals and fresh sources of energy.

Such possibilities depend entirely upon the location of such a shaft. Geological observations show that although it might be possible to encounter oil and coal in the shallower levels, and radium, gold, and diamonds at greater depths, there is no assurance at all that any of the precious mineral deposits would be encountered by a shaft sunk from the surface almost at random. Aside from the very small chance of such an enormous investment producing any commensurate returns, the practical engineering difficulties of sinking such a tremendous shaft are actually insuperable. In the first place the great

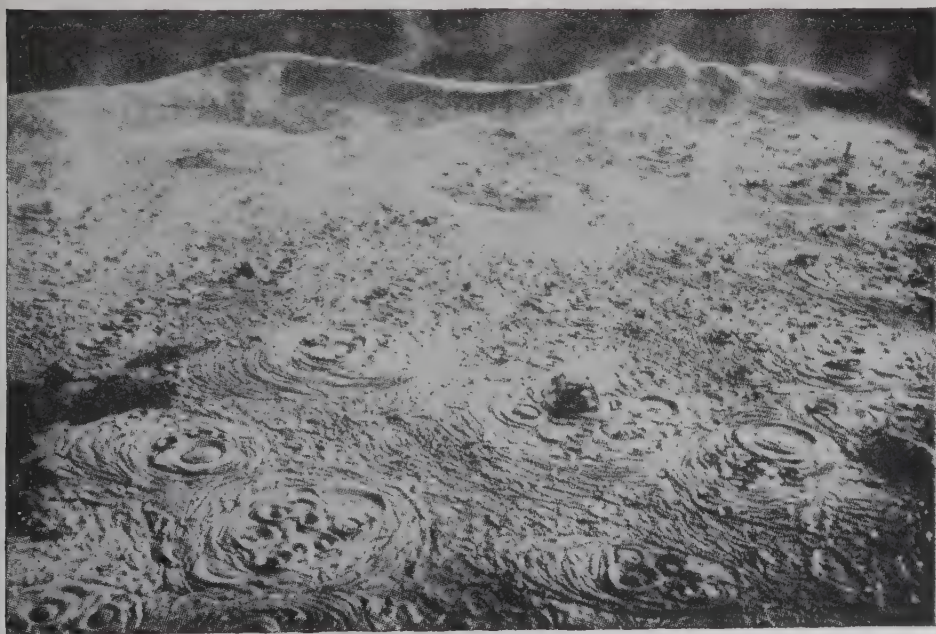


Fig. 15. Boiling mud in the crater of a well known mud volcano located at Tiketere, New Zealand

rock pressure would cause any hole, even a small one, to collapse at a depth of 12 miles, and to maintain an open shaft large enough for mining operations is quite impossible. Another major difficulty in the way of carrying out such an enterprise would be to control the temperature, for, generally speaking, it may be said that water would boil at a depth of two miles and iron and other tools would be too hot to handle, even if

it were possible to keep the atmosphere cool enough for the men to work.

HOT SPRINGS AND GEYSERS

We can understand now whence the water spouted by hot springs and geysers gets its heat. In Yellowstone Park, within an area of about 800 square miles, there are over 3,000 hot springs, the water coming to the surface at varying temperatures. Hot springs are numerous, too, in Mexico,

Iceland, Italy, New Zealand, and elsewhere—in fact in nearly all parts of the world where there are active volcanoes, or in regions where the mountains have been formed by volcanic activity. In New Zealand many of the thermal springs are filled with hot mud deposits. Known locally as the “Porridge Pots,” the mud within may actually be seen to boil (Fig. 15). The Maoris use the hot springs for cooking their food.

In Alaska the Valley of Ten Thousand Smokes is fairly peppered with hot springs and vents, from which live steam escapes. In this place one may cook his food in the steaming vent and preserve it when cooked in nearby snow drifts.

Hot water is ejected through vents in the earth's crust to form geysers as distinct from springs. The best known



Fig. 16. The Pohutu Geyser at Whakarewarewa, in North Island, New Zealand. It is the largest in the world the water being ejected to a height of 500 to 1,500 feet at regular intervals

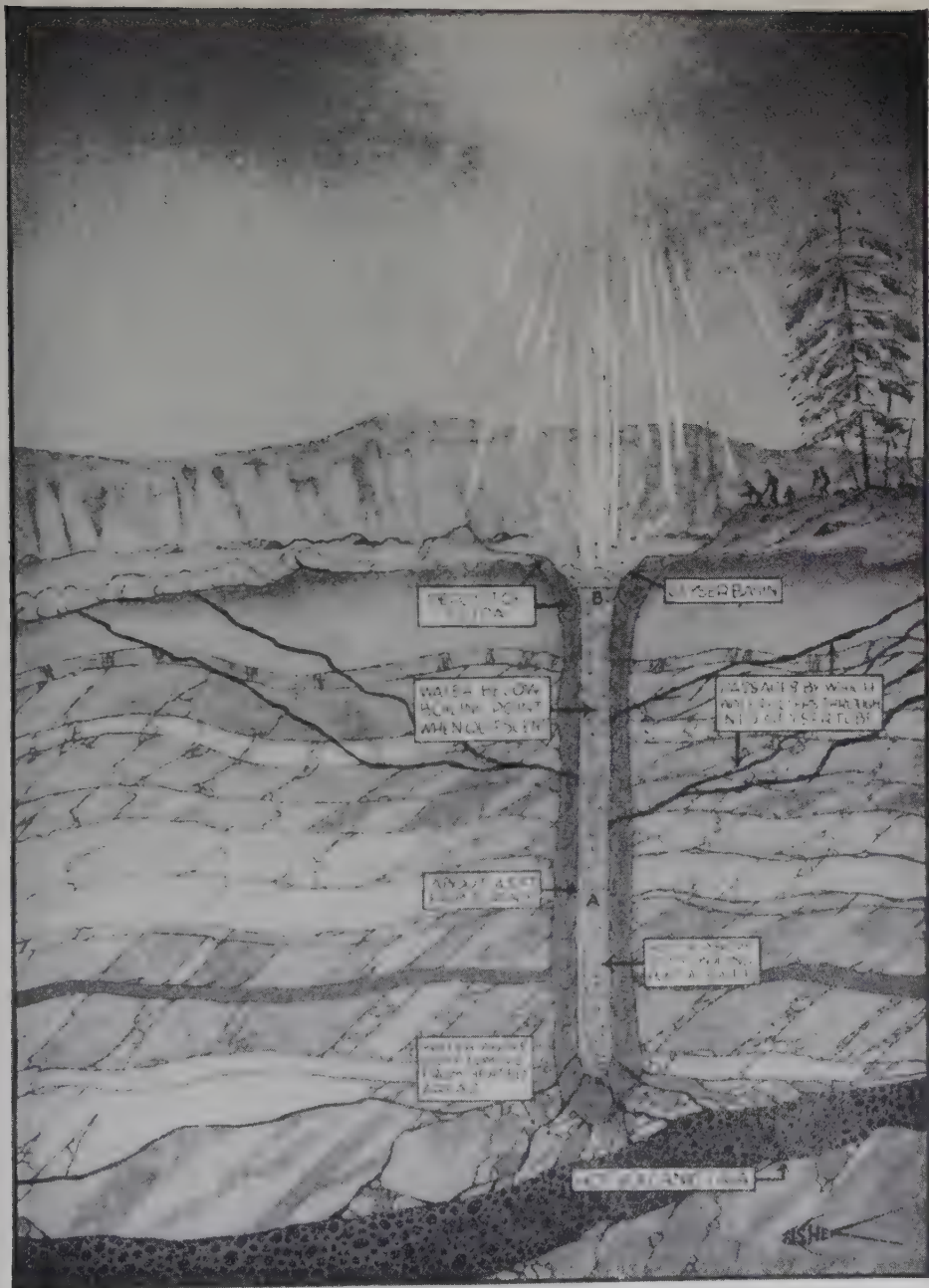


Fig. 17. Sectional details showing the working of "Old Faithful" geyser in Yellowstone Park. A picture of the geyser, probably the most famous in the world, in full action is seen on page 86 and an account of its workings is given on page 112

geysers are found in New Zealand, Yellowstone Park, and Iceland. Most of these natural fountains have a regular intermittent activity. Water accumulating in a subterranean chamber in which the temperature is above the boiling point, is converted into steam as in a boiler. Provided the outlet is restricted or temporarily blocked, then the temperature of the water may rise about the boiling point without being converted into steam. It is superheated water. Superheated water is only possible under confining pressures; as soon as the pressure is released all the superheated water changes into steam. If such a release is rapid or sudden the steam expands with explosive violence. The subterranean channels beneath a geyser vent are so restricted that the water accumulates at superheating temperatures. Where the rocks are hot enough the pressure is ultimately so great that it overcomes the pressure due to overlying water, and the whole column of water bursts explosively into steam. This causes the geyser eruption. The process is repeated at intervals which depend on the length of time required to convert the next supply of water into steam.

WORLD'S LARGEST GEYSER

The largest geyser in the world is Pohutu, at Whakarewarewa, in North Island, New Zealand (Fig. 16). It has a "pipe" 80 feet in length and ejects a column of water to a height of from 500 feet to 1,500 feet. In the Wairakei Valley is the Champagne Cauldron, spouting columns of effervescing water into the air every few minutes. Here, too, is the Great Geyser that spouts to a height of 30 feet every 10 minutes. The Crow's Nest

similarly shoots boiling water to a height of 40 feet every half hour.

In Iceland the original geyser is still active. All other geysers of the world are named after that which was named by the Icelanders the "Geyser." This word in English means literally a gusher. The Icelandic geysers were the first to be studied by men of science, and today remain, quite properly, the type for all others.

There are over a hundred active geysers in Yellowstone Park, including the Giantess that "obliges" at intervals of 10-20 days, spouting to a height of 200 feet for a period lasting from 12 to 36 hours. Here, too, is the best known geyser in the world, "Old Faithful," so called because of the regularity of its performances (illustration on page 111). For the past 30 years it has regularly spouted for four minutes at a time a column of boiling water and steam to a height of about 150 feet every 60 to 80 minutes. At each "spout" over 1,500,000 gallons of water are ejected, equaling over 33,000,000 gallons every day.

This intermittent type of geyser is believed to owe its activity to the sudden generation of steam, caused by the general rise in temperature of the water in the pipe. As we have already seen, the boiling point of water at sea level is 212° F., but this boiling point rises with depth. Referring to Fig. 17, we see that the geyser tube is filled with water that percolates into it from fissures. Hot water also enters the tube A from below, its temperature being considerably above boiling point from its contact with the heated lava and rocks deep down below the crust. This water at A cannot generate steam because of its great pressure and because of the cooler water in B in the column

above. This superheated water rises and reaches a point (about 45 feet below the surface) where steam can be generated due to the decreased pressure. Steam under pressure has tremendous energy—steam heated to 100° C. requires 1,650 times the space of water at the same temperature—and the sudden conversion of superheated water into steam blows the 45-foot column of water high into the air. It falls in the basin and the column fills again, to repeat the process with clockwork regularity as long as the conditions remain the same.

WHAT IS A VOLCANO

Volcanoes are similar to geysers in their action, except that they eject lava or molten rock, ashes, and steam in great quantities instead of water. They are openings in the earth's crust that act as safety valves for the forces below, releasing them in a measure when they become too great for the earth's crust to withstand them. The volcanic matter is thrown out through a pipelike passage or vent, which is the volcano proper. The ejected material falls around the volcano as water falls around the jet of a fountain. This material accumulates into a cone, the top part of which—generally basin-shaped—is called the crater of the volcano.

There are about 1,000 volcanoes in all, of which about 350 are on the "active list." Fortunately there are no active volcanoes near the thickly populated parts of the United States. Lassen Peak in California is our only active volcano at all, although within the last thousand years many were active in Idaho, Nevada, and Utah, and many still are active south of the Rio Grande in Mexico. Alaska and the Aleutian Islands afford many examples of active and quiescent volcanoes. Many of our finest mountain

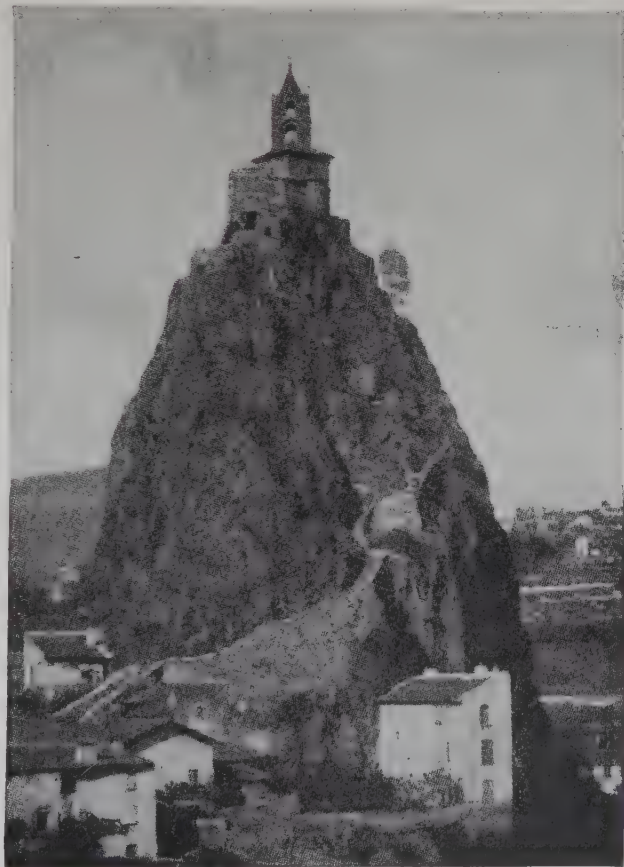


Fig. 18. St. Michael's Chapel at Le Puy, France. This peculiar hill was once the "pipe" of a volcano. The softer rocks have all worn away, leaving only the hard core

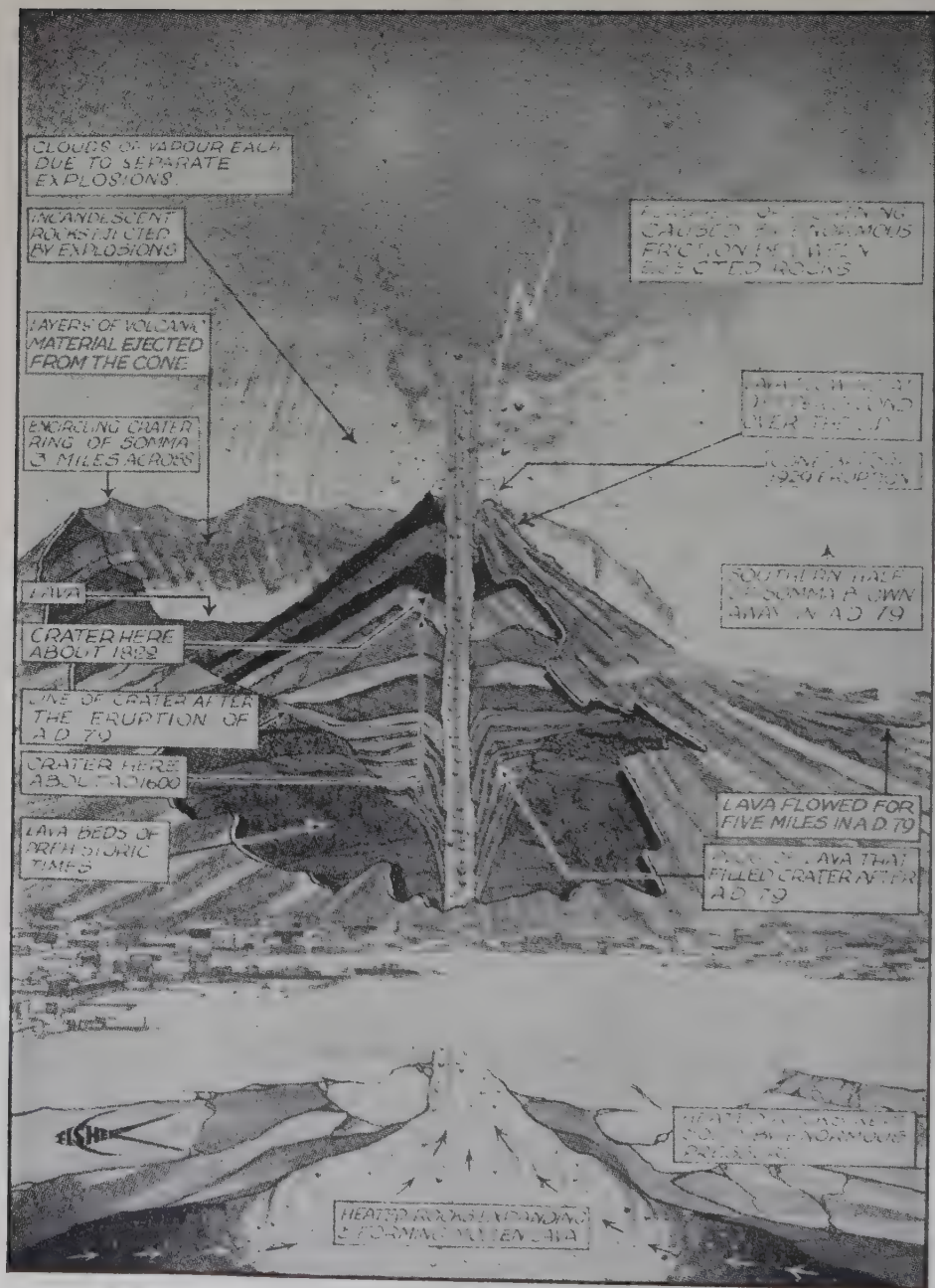


Fig. 19. A sectional view showing the probable interior arrangement of Mount Vesuvius. The changes that took place in its cones and lava channels after the earthquake of A.D. 79 that destroyed Pompeii and Herculaneum, can clearly be seen

peaks such as Rainier, Hood, Baker, Adams, and Shasta are relatively recently extinct volcanoes. At least we hope they are extinct. Crater Lake in Oregon is the lower part of a huge ancient volcano, the top of which collapsed into the crater.

The Hawaiian Islands were made by volcanic eruption, and even today furnish examples of so-called quiet volcanoes which are almost continuously active in a subdued manner, but which occasionally rise to heights of great activity resulting in huge lava outpourings.

The active volcanoes of the Andes, of the Dutch East Indies, of Japan, and of southern Italy are a constant menace to human life and property.

In France, Germany, and Great Britain there are numerous examples of ancient rocks, now more or less eroded away. A truly remarkable volcanic relic is the hill on which is perched the Chapel of St. Michel at Le Puy in France. The hill is the pipe of an extinct volcano, the lava having solidified in the pipe (Fig. 18).

Certainly the best known European volcano is Vesuvius, overlooking the Bay of Naples in Italy. Fig. 19 shows its probable interior arrangement. Before the eruption of 1906 the mountain was 4,200 feet in height, but now it is 3,660 feet. The present cone stands a little to the south of the center of the older crater which

is a walled plain a mile or more in circumference. It was by this volcano that Pompeii was buried beneath a torrent of volcanic ash in A.D. 79, and two other cities, Herculaneum and Stabiae, were destroyed, over 200,000 people losing their lives. Then for nearly 1,500 years Vesuvius was quiet, until in 1631 there was another eruption. Streams of lava flowed down the mountain, and clouds of dust ejected from the crater were carried as far as Constantinople. Great streams of mud reached to the Apennines and 18,000 people were killed. Since that time the volcano has been more or less active in varying intervals—in 1906 two villages were overwhelmed by ashes; at Naples the ashes were three feet in depth.



Fig. 20. Krakatoa island in Sunda Strait off Sumatra; the scene of the world's greatest explosion in 1883 when two-thirds of the island were hurled into the air.



Anders & Co.

Fig. 21. Since the destiny of Japan is so closely connected with her volcanoes, the Japanese have conducted extensive investigations to study the craters

THE KRAKATOA ERUPTION

We can refer here to only a very few of the eruptions which have shown how violent are the forces of the earth's interior. Mention must be made, however, of the world's greatest explosion, the one that occurred on the island of Krakatoa, in the Straits of Sunda, near Sumatra, in 1883. On the island was—and is—a volcano which at that date was considered extinct; but in the spring of the year there were deep rumblings and earthquakes that heralded the cataclysm. Every day the noises increased until they could be heard at a distance of 20 miles. A dark cloud of dust hung over the island, causing day to be as dark as night for hundreds of miles around. The water around the island became so hot that shoals of fish were killed. By the middle of August the darkness had become general over the Strait and neighboring coasts and there were repeated earthquakes. There were terrifying sounds similar to artillery fire, accompanied by crackling noises caused by the impact of fragments of rock as they were hurled up out of the volcano.

On August 27, 1883, there were two or three explosions, and these were followed by a frightful convulsion that tore away two-thirds of the island and hurled a cubic mile of material high into the air. Enormous quantities of pumice and ash were scattered over a wide area, being in many places so thick that vessels could not move through the seas in which the material was afloat. So extensive was this distribution of ejected material that ashes fell on a ship 1,600 miles from Krakatoa. Great waves were caused in the sea, one of which

reached over 50 feet in height on the neighboring coasts. It traveled over half the globe and actually reached the coasts of England and France. The devastating wave caused great destruction of life and property in the area around Krakatoa, and swept away all lighthouses and familiar landmarks along the coasts. Nearly 300 villages were destroyed and over 36,000 people perished.

The eruption at Krakatoa—where the volcano is still active (Fig. 20)—was undoubtedly the most severe explosion of modern times. It was probably caused by water from the ocean finding its way into the interior of the earth, through fissures opened up by the preliminary earthquakes. The center of the island collapsed in a preliminary explosion, and the waters of the ocean, gaining free access, met the molten material rising from below. The immediate conversion of the superheated water into steam resulted in what was virtually a gigantic "boiler explosion."

USE OF VOLCANIC ENERGY

To harness all this volcanic energy for human use has been the ambition of many men. In Iceland the steam from hot springs has been used for years for heating schools and public buildings, and this could be done in other regions having hot springs. In 1904 Prince Ginori-Conti began to operate an engine with the steam escaping from a natural vent in Larderello, about 60 miles north of Rome. By 1929 the power plants had been made large enough to produce 12,000 kilowatts.

Various tests were made by the Italians at Pozzuoli, near the base of Mount Vesuvius, and by Americans in Oregon and California to find greater sources of steam power which

might be brought into commercial development. Unhappily one of the Italian power plants was engulfed by collapse of the surface and not only the building and machinery were lost but all the men working in the plant.

This tragic and complete loss naturally has checked further enterprise along these lines. It is safe to assume, however, that in time such projects will be revived, and that reasonable success will follow.

CHAPTER 7

TIME AND TEMPERATURE

PERHAPS the most important application of the earth's rotation is in the measurement of time. The interval between one noon and the next is the solar day, and this is divided into 24 hours, and these again into 60 minutes. In the days before clocks, the passage of time was measured by sundials, noon being when the sun reached its highest point in the heavens for the day. Although a clock will measure 24 equal hours from noon to noon, it does not agree with a sundial as to the time when the sun is highest in the heavens at different times of the year, for the clock measures 24 equal hours throughout the 365 days. As the earth moves at different speeds in its yearly journey round the sun—later we shall explain why this is so—the sundial and the clock do not exactly agree. The amount of the difference between them is known as the "equation of time."

In olden days people supposed that the sun moved round the earth and they determined its apparent pathway among the stars. This belt of stars they called the "zodiac," from a Greek word meaning "animal circle," because several of the 12 constellations in it are known by the names of animals. Later Copernicus suggested, and Galileo demonstrated, that it was the earth that traveled around the sun. It is this movement that causes the stars to rise four minutes earlier each night.

The time taken for the sun to make its apparent journey through the zodiac is known as the sidereal year. Its length is roughly $365\frac{1}{4}$ days—actu-

ally, of course, this is the time required by the earth to make a complete revolution in its orbit around the sun. In determining the length of the year we disregard the odd quarter of a day—which would otherwise cause considerable inconvenience—and give the year the round number of 365 days for three successive years. We give every fourth year 366 days, however, and this is called "leap year," the extra day being gained from the four quarter-days left over. Thus any year the date of which will divide by four is a leap year except the first year of a new century.

THE ODD QUARTER-DAY

Without going too deeply into the matter, we may say that the odd quarter-day is actually only of 5 hours 48 minutes 46 seconds duration. As it is about $11\frac{1}{4}$ minutes short of a quarter-day of 24 hours, a whole day will be gained in 129 years, irrespective of the allowances made for leap year, and in 400 years this will amount to three days. It was Pope Gregory XIII who decreed, in 1582, that the matter should be adjusted by making only such century years as are divisible by 400 leap years. Thus, although the year 1900 is divisible by four, the year 1900 was not recorded as a leap year because it is not divisible by 400 and there was no leap year between 1896 and 1904. At the time of this decree there was an accumulated discrepancy of 10 days, so Gregory decided that the calendar should be corrected by dropping 10 days, October 5, 1582, being called October 15th.

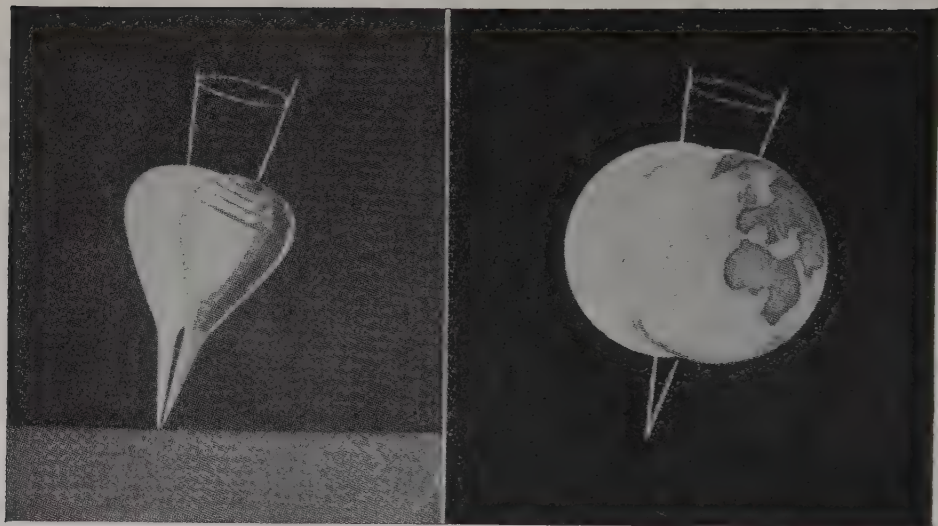


Fig. 1. When a peg top (left) spins, it wobbles on its axis. So does the earth (right). This movement, called precession, takes 26,000 years to complete one revolution. As a consequence of precession, the positions of the Arctic and Antarctic circles are gradually changing

The Gregorian calendar was adopted by all Catholic countries, but the Greek Church and the Protestant nations would not recognize the decree. In 1752, however, England came into line by changing September 3rd to September 14th. In the same year another matter was put right when the year was reckoned to commence on January 1st instead of March 25th as had long been the rule. The former change was so resented by many people that there were riots in various parts of the country, the people imagining that they had been robbed of 11 days, and that the Act of Parliament was merely a means of extorting 11 days more rent or interest than what they actually had to pay!

Incidentally, if our present valuation of the solar year is correct, the error in the Gregorian calendar will amount only to one day in about 3,320 years.

Everyone has noticed that as a peg top rotates on its axis, its axis also slowly rotates as it spins (Fig. 1). This movement, called "precession," is due to the effect of gravity and will continue as long as the speed of rotation is maintained. Now the earth is spinning in a similar way at a high speed, and—so far as we can tell—as it is in a perfect vacuum, the motion should go on forever, since there is no friction to retard it. It spins at the rate of one rotation a day, and, like the peg top, it also "wobbles," or precesses, on its axis. This results in the North Pole rotating in a small circle, so that it points to a new part of the sky as time goes on. The effects of precession are not great enough for us to detect casually for a single rotation requires 26,000 years to complete.

For surveying, the apparent change in position of the North Star is important. Corresponding corrections

must be made when explorers or navigators are determining their positions by observations on Polaris, the North Star. The correct apparent position of Polaris for every hour of the year, for all latitudes, is listed in a government publication known as the "Nautical Almanac." Several national governments, including that of the United States, publish this information, which obviously is essential to navigation throughout the world.

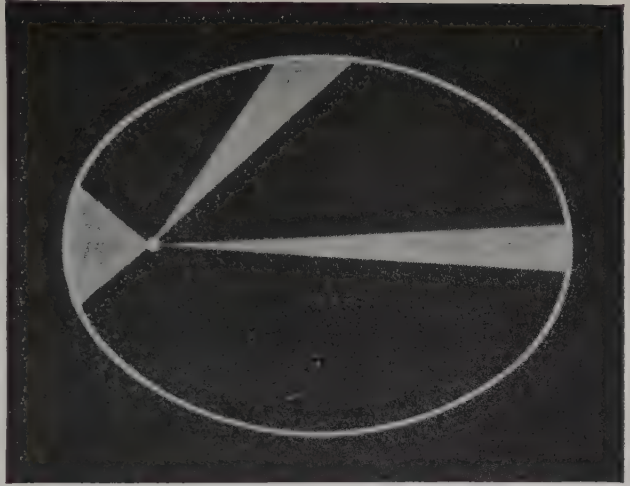


Fig. 2. Kepler's second law of motion states that a line drawn from the sun to a planet moves over equal areas in equal periods of time

VARYING SPEEDS OF THE EARTH

We mentioned in an earlier paragraph that the earth moves at different speeds at different points in its orbit. This is due to the orbit being slightly elliptical and is in accordance with certain laws of motion formu-

lated by Kepler. His second law states that a line drawn from the sun to a planet moves over equal areas in equal periods of time, no matter whether the planet is traveling over the part of its orbit that is nearest to, or furthest away from, the sun.

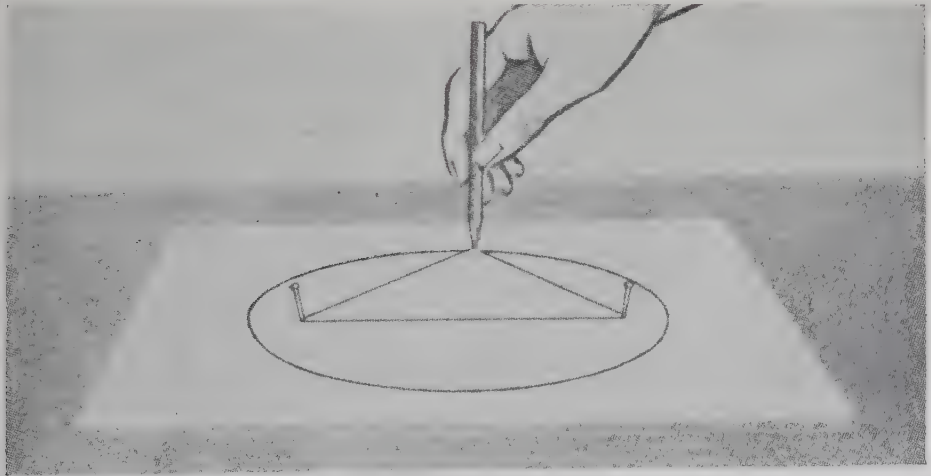


Fig. 3. Drawing an ellipse with two pins and a piece of string. The further the pins are apart, the greater is the degree of ellipticity. The orbit of the earth round the sun is not a true circle, but is slightly elliptical

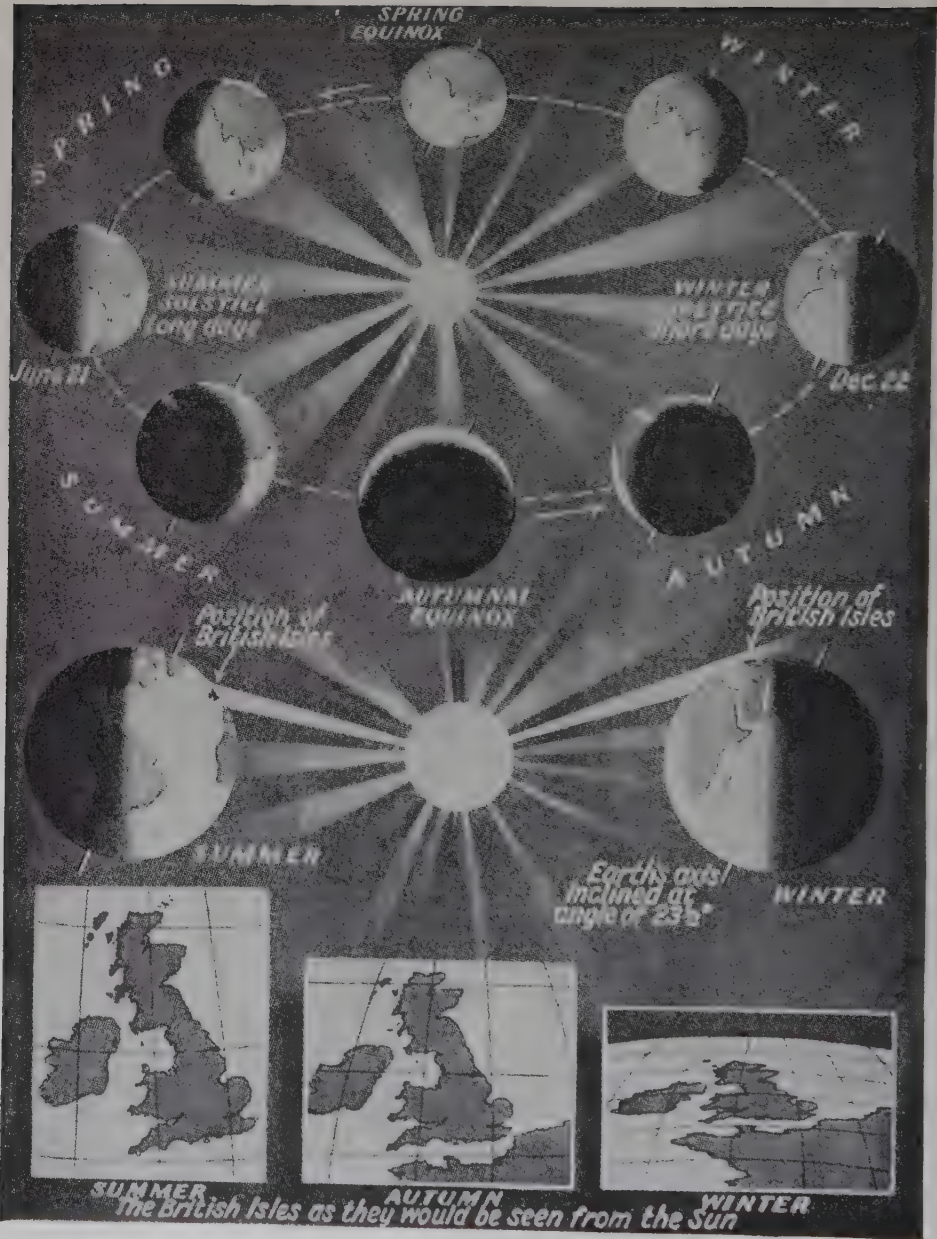


Fig. 4. The seasons of the year depend entirely on the degree of the inclination of the earth's axis

Thus, as the orbit of the earth is elliptical in shape it follows that the earth must move more quickly when it

is near the sun, as is shown in Fig. 2. An ellipse, which is a foreshortened circle, can be drawn by fixing two

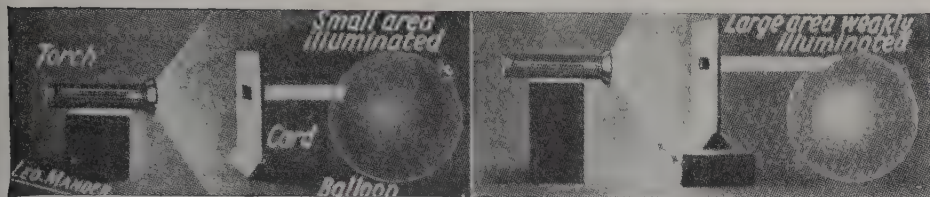


Fig. 5. The effect caused by the different angle at which the sun's rays may strike a particular part of the earth. This effect is shown diagrammatically in Fig. 7

pins in a drawing board, and passing over them a piece of string (Fig. 3). A pencil placed in the loop, so held that the loop is kept tight while moving the pencil, will result in the drawing of an ellipse, the shape of which depends on the distance between the two pins. These pins mark the *foci* of the ellipse. Actually, the earth's orbit is only very slightly elliptical and only a very little different from a circle. The sun is at one of the foci.

The distance of the earth from the sun varies by about 3,000,000 miles at different points in the orbit. The mean distance is 92,900,000 miles, to cover which it would take a high velocity

shell nearly five years. It is a curious fact that the earth is nearest to the sun at the beginning of the year, and furthest away in July. It is obvious, therefore, that distance alone does not determine the seasons, otherwise we should experience the hottest weather in January and the coldest in July.

The amount of heat received by any one part of the earth's surface is determined much less by the distance the earth is away from the sun than by the inclination of the earth's axis, and whatever may be the position of the earth in its orbit, its axis is inclined at an angle of $66^{\circ} 32'$ to the plane of the orbit (Fig. 4). It is for-

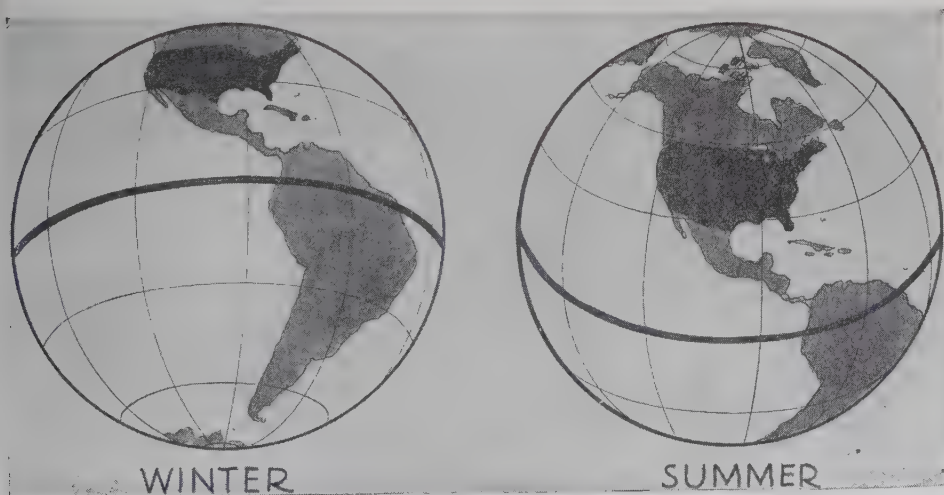


Fig. 6. The northern hemisphere is tipped away from the sun in the winter and toward it in the summer

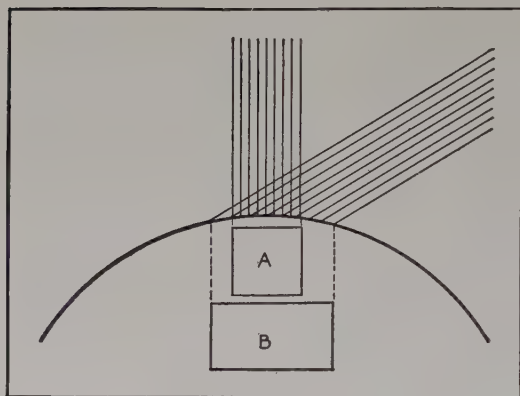


Fig. 7. The difference in area covered by similar beams of sunlight falling on the earth (a) vertically, and (b) at an angle

tunate that the axis is so inclined, for were it always vertical there would be no seasons, and the days and nights would be of equal length all the year round. As a result of this inclination of the earth's axis, however, only on March 21st and September 23rd are the day and night of equal length all over the world. On these two dates, the North and South Poles are equally exposed to the sun's rays and receive an equal amount of heat.

THE TWO SOLSTICES

After the spring equinox, however, the northern hemisphere inclines increasingly towards the sun, and the southern hemisphere inclines away from it to a corresponding degree. Spring gives place to summer in the north, and on June 21st comes the longest day, corresponding to December 22nd when there is the longest night. The former is known as the "summer solstice" and the latter as the "winter solstice."

In summer in the northern hemisphere the sun rises east by north and sets west by north, whereas in March and September it rises due east and

sets due west, but is not so high in the heavens at noon (Fig. 6). In winter it rises east by south, sets west by south, and at noon is low in the sky. At midsummer, as apparently it has to travel over a large arc of the sky, it is above the horizon for 16 hours; at the spring and autumn equinoxes, for 12 hours; and at midwinter for only about eight hours (Fig. 6). During the northern summer, it is winter in the southern hemisphere. After June 21st the days grow shorter in the northern hemisphere and longer in the southern hemisphere, which now receives an increasing amount of sunlight. At the winter solstice there are short days and long nights in the northern hemisphere, and the further north one goes the shorter are the days. At the shortest day the sun is above the horizon for seven and three-quarter hours at Vancouver, B. C., and for five and three-quarter hours at Valdez, Alaska, and the Straits of Belleisle, Newfoundland.

WHY IT IS HOT IN SUMMER

So much for the periods of time during which the sun is above the horizon. To explain in greater detail why it is hotter in summer, even though the earth is 3,000,000 miles further away from the sun, we may refer to Figs. 5 and 7. These illustrate that the amount of heat received at any given place is regulated by the angle at which the sun's rays fall. When the rays fall vertically on the land we are receiving their full power, but when the rays are inclined—owing to the greater inclination of the earth on its axis—we receive proportionately less heat, for the same rays have to

cover a larger area of the earth's surface.

We shall be better able to understand this by imagining that we have a beam of sunlight a mile square. If this falls vertically on the earth it will cover and warm a square mile of land, but if it reaches the earth at an angle it has to cover an area the smaller sides of which are a mile in length while the other sides are proportionately longer. As there is exactly the same amount of light—and heat—radiation in each beam, it follows that in the latter case a given area of land will receive a smaller quantity than in the former case and that the heat and light will be correspondingly diminished. The principle is illustrated also in Fig. 7.

If the sun's rays are inclined at an angle of 50° , only 64 per cent reaches us; at 10° , only six per cent. At noon

on midsummer's day, in latitude 52° N. the sun's rays have an inclination of $61\frac{1}{2}^{\circ}$ to the horizon, whereas in midwinter the inclination is $14\frac{1}{2}^{\circ}$ to the horizon. Observations at the latitude of northern Newfoundland show that there is nine times as much sunlight at nine o'clock on a June morning as there is at the same hour on a January morning. At noon there is four times as much in June, and at three o'clock nearly ten times as much.

A very important factor in reducing winter solar temperatures at high latitudes is the absorption of radiant heat by the atmosphere itself. A content of dust and high humidity are both powerful influences in reducing the amount of radiant heat which reaches the earth's surface. It follows from the previous paragraph that the sun's rays pass through a longer course in the atmosphere at low angles of inclina-



Fig. 8. A picture taken at midnight from Abisko on Lake Tornetrask in Lapland

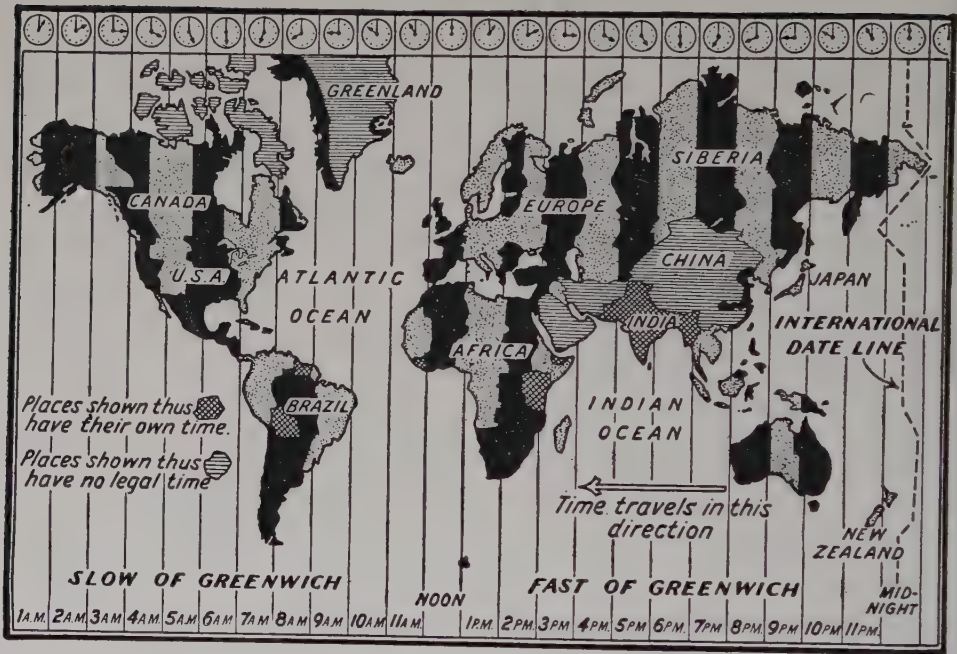


Fig. 9. In 1884 the world was divided into twenty-four time zones, each fifteen degrees apart. There is an hour's difference in time between each line. Some countries do not keep to zone time

tion than at high angles, thus reducing the amount of heat received by that part of the earth's surface.

Every morning between the winter and summer solstices the sun rises, and every night it sets, a little further to the north. Every day at noon it reaches a little higher in the heavens, until on June 21st, the longest day, it is above the horizon for about 18 hours, rising in the northeast and setting in the northwest. At midnight it is only a little distance below the northern horizon as seen from London. At Perth, Scotland, five degrees north of London, the town clock can be read by natural light at midnight.

THE MIDNIGHT SUN

We have only to travel further north to reach the "land of the mid-

night sun." Here, at places situated beyond the 66th parallel of north latitude—such as the northern parts of Sweden, Norway, Russia, Greenland, Canada, and Alaska—during the summer the sun does not sink beneath the horizon at all, even at midnight (Fig. 8). Naturally, such a state of affairs is of the greatest assistance to polar explorers, who take full advantage of the long stretches of continuous sunshine. This long period of unbroken daylight is counterbalanced by the long polar night, however, when there is a period during which the sun does not rise above the horizon for months on end. At such times, however, the starlight, aided by the snowy landscape, keeps the land very far from complete darkness. It is more like deep twilight.

The native Eskimos who are used to these long stretches of light in summer, and twilight or darkness in winter, develop very un-European habits. Explorers and other scientists have frequently been annoyed by the unpredictable manner in which Eskimo dog drivers quit traveling to sleep or eat with no regard to the white man's clock. It seems that our orderly habits, in which we take pride, may possibly be a result of environment as much as of human character.

The circumpolar night makes especially spectacular the displays of "northern lights," *aurora borealis*, and the *aurora australis*, as the corresponding phenomenon in the southern hemisphere is called. There are wonderful floods of hazy and delicately colored light, which stretch from the horizon far past the zenith. The light in great beams or clouds seems to swing about a polar axis across the whole sky, sweeping up and outwards from the Pole, and oscillating like great fronds of light to and fro. This has long been recognized as an electro-magnetic phenomenon, connected with the magnetic poles of the earth and its axial rotation.

From time to time the electrical state of the earth's atmosphere is affected by enormous electrical disturbances shot out from the sun at time of sun spot activity. On March 25, 1940, telegraphic and radio transmission between America and Europe was completely disrupted by the solar electrical discharges, and large areas of the eastern United States and Canada were without telegraphic communications for several hours for the same cause. The great electrical disturbance accompanied a particularly brilliant display of *aurora borealis*, which was visible as far

south as N. 42° in the middle west of the United States. Such phenomena are rarely visible so far away from the poles.

THE HARVEST MOON

We may here refer to the fact that some people think there is more moonlight in the autumn than at any other time of the year. This belief is an actuality, and is due to a phenomenon called the "Harvest Moon." The explanation lies in the fact that the full moon at the autumn equinox is in that stretch of its orbit where it is moving north most rapidly. For the best part of the year the moon rises some 45 minutes later each night, but when it is moving north the time is diminished, so that it rises only a few minutes later each evening. It may be that the time of rising is only an hour later in five days instead of nearly four hours (i.e. 45 minutes $\times$ 5). Conversely, at the March full moon, when the moon is moving south in its orbit, the times of rising may be quite as much as one and one-half hours later each night.

This increase in the duration of the moonlight reaches its maximum when the full moon is moving north, for it rises about sunset on several successive evenings. It is above the horizon for most of the night, thus allowing the farmers to work longer—should they wish to do so!—than if the night were dark. The Harvest Moon is always the full moon that falls nearest to the autumnal equinox (September 23rd). Often the Harvest Moon is seen just after sunset hanging like an orange ball low in the sky. This is because in early autumn the horizon is mostly clear of mist or cloud.

In the preceding paragraphs we have had occasion to refer to latitude

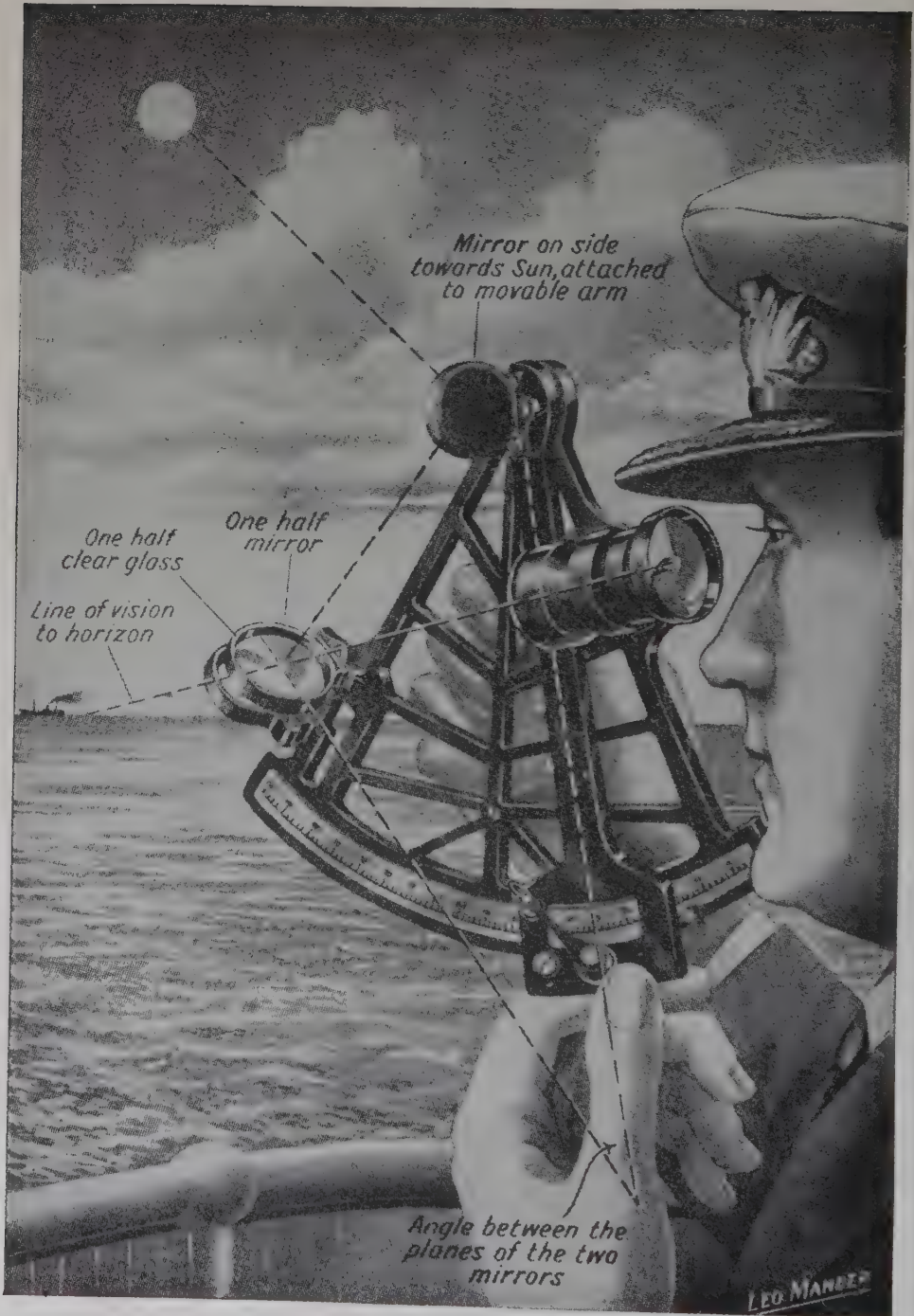


Fig. 10. How a sextant is used to find the angle of the sun's altitude. (See text)

and longitude, and it will be opportune here to make a brief reference to the means by which we are able to define points on the earth's surface—as, for example, when a geographer wishes to state precisely where a village or town is located, or a captain wishes to say exactly where his ship is on the ocean. For such purposes the earth's surface is divided by lines of latitude and longitude. The northern and southern hemispheres of the earth meet at the equator, which is half way between the poles. Then circles are drawn parallel to the equator, and are known as parallels. They lie, of course, in planes which are at right angles to the earth's axis. Corresponding circles drawn perpendicularly to the equator and through the poles are called meridian circles. Do not forget that whereas the parallels of latitude are the same distance from each other all round the earth, the meridians of longitude all converge at the poles. To fix the position of a town or a ship it is first necessary to know its position with respect to a meridian circle and a parallel of latitude.

All meridian measurements are made from the meridian that passes through Greenwich, this being "longitude 0°." The corresponding meridian at the other side of the earth may be called either 180° E. or 180° W. Half-way between this and longitude 0° are 90° E. and 90° W. In measuring latitude, the equator is taken as the zero parallel, and the other parallels are respectively north or south latitude, and are also measured as being north or south of the equator, so that the latitude of New York is written 41° N. The exact position of New York is 41° N. 74° W. Let us now see how the captain finds the position of his ship at sea, where there are no

familiar landmarks to give him any indication of his whereabouts.

HOW A SHIP'S POSITION IS FIXED

To obtain the longitude of a ship's position it is necessary to discover the "local time" (Fig. 9) and compare it with the time of day at Greenwich, which is registered by a very accurate clock called a chronometer. The principle is as follows: the sun makes its apparent daily journey round the earth from east to west in 24 hours and the earth is divided into 360 meridians of longitude. Each meridian represents, therefore, four minutes of time. Now, if by the chronometer we know that it is noon at Greenwich and we discover that the local time is 5 p.m. we can calculate our longitude as being $\frac{5 \times 60}{4}$ degrees east, because

we are five hours (300 minutes) ahead of Greenwich and four minutes represents one meridian of longitude. We are, in fact, in longitude 75° E. If the local time were 7 a.m. we should be in longitude 75° W.

For any time of the day the local time may be determined by the true direction of the sun's beams, using a compass to indicate true north and a sundial for the sun's position. The exact local noon is when the sun reaches its zenith, at which time the sun, the observer, and the North (or South) Pole are in line. This instant gives not only the true local noon time, but also the true N-S direction. The time at which the sun rises to its zenith must be observed with the aid of a sextant or similar instrument for measuring vertical angles.

The principle of latitude is as follows: if the sun is directly overhead at the equator, then the angle made at-noon by the sun, your ship, and the

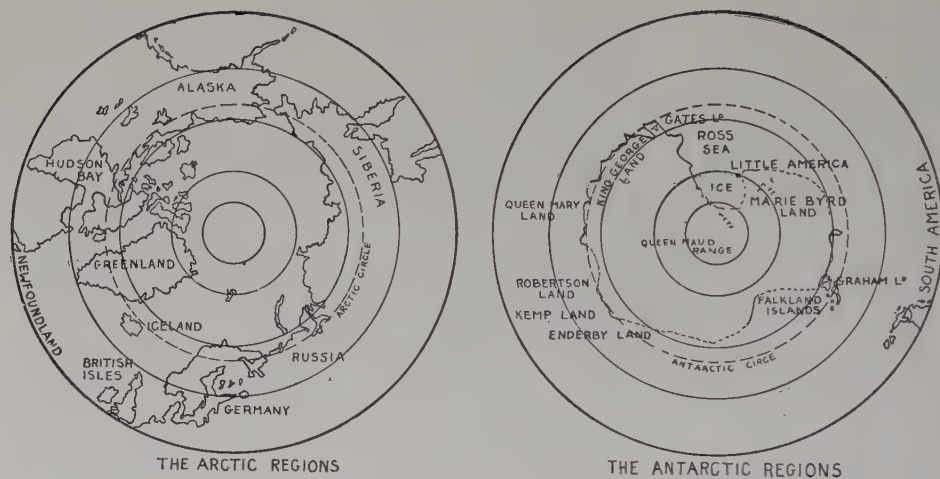


Fig. 11. Maps indicating the distribution of land areas in both the Arctic and Antarctic regions

horizon, will, if subtracted from 90° , give the latitude. The angle between the sun, ship, and horizon is called the sun's "elevation," and the angle of elevation subtracted from the vertical yields the "departure." The sun, however, is only overhead at noon at the equator on two days of the year; therefore, to find correct latitude, it is necessary to add or subtract from the angle of departure the latitude at which the sun actually is vertical at noon on that particular day. This angle has been carefully calculated for every day in the year and is published in tables in the *Nautical Almanac*.

To find the altitude of the sun—that is, the angle of sun, ship, and horizon—a sextant (Fig. 10) is employed. The sextant telescope must be so held that a line from eye to horizon passes through the edge of the mirror. The arm of the sextant is then moved so that the upper mirror reflects the sunlight on to the same edge of the lower mirror. From the scale can then be read the angle between

the mirrors. This angle, doubled, gives the required figure.

TEMPERATURE IN THE ARCTIC

If we draw a circle of $23\frac{1}{2}^\circ$ radius around each Pole we shall include in it the polar regions. Over extensive areas of both the Arctic and the Antarctic zones (Fig. 11) are great masses of perpetual ice and snow that decrease only a little during the summer and fully regain any loss during the winter.

In the north polar regions the temperature line does not run truly parallel to the Arctic circle, for the great masses of land in the northern hemisphere, and their influence upon ocean currents, affect the temperature. In the southern hemisphere, however, where there are no continents close to the polar regions, the temperature line runs roughly parallel to the line of latitude.

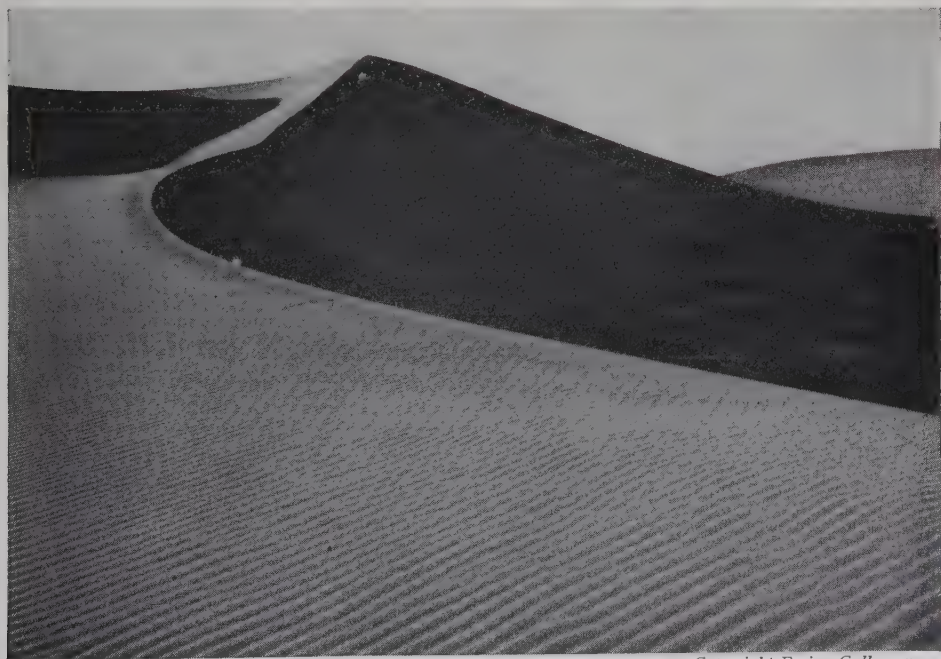
Although the sun is above the horizon at the Poles for six months continuously, it is never really hot there, because of the extremely oblique an-

gle at which the rays reach the earth, as explained by Fig. 7. At the Poles, the sun never rises to more than $23\frac{1}{2}^{\circ}$ above the horizon, so that even in the most favorable of circumstances, the sun is only about as powerful as it is in the northern United States at sunrise or sunset.

Another reason for the low temperature of the polar regions is that a large amount of the heat is taken up in melting and evaporating the ice and snow of these regions. The long winter of six months, furthermore, tends to counteract the effect of the long summer daylight.

The Poles do not, however, give us a record for low temperature, for the lowest air temperature yet recorded for polar zones, -76° F., was exceeded by the -94° F.—or 126° of frost—recorded in February, 1892, at

Verkhoiansk in Eastern Siberia, just outside the Arctic circle. The average January temperature at Verkhoiansk is -56° F. and the highest January temperature on record rises all the way to -13° F. Before the Russian Revolution, and probably after it as well, this region was used as a place of exile for political suspects. The horror of going to the place and the agonies of those doomed to live there, in 100° or more of frost, can be better imagined than described. The Soviets have settled people in this region, too, though probably not in the coldest part. When they began to build houses they found that the walls fell down, because the heat of the house stoves thawed the earth beneath the floors. This had never been thawed before, so it brought about a subsidence. Today the floors are



Copyright Ewing Galloway

Fig. 12. The channeled sand of Death Valley makes a beautiful picture, but when the temperature rises to 134° F. you become conscious of the heat, not the beauty

raised, thus effectively insulating the soil from the warmth of the houses.

At Irkutsk in Siberia (50° to 52° N. Lat.) the mercury freezes as early as November. Because of this fact, temperatures such as these in Siberia cannot be measured with an ordinary thermometer and instead they are taken with a spirit thermometer which will not freeze at any temperature to which the atmosphere can fall.

SOME REALLY HOT SPOTS

Similarly the hottest places in the world are not at the equator. The highest temperature ever recorded in this hemisphere, 134° F., was in July, 1913, at Death Valley, California. Death Valley is 36° N. of the equator, more than one-third of the way towards the Pole, but it lies 264 feet below sea level; it is pocketed within a circle of mountains, and usually in summer becomes extremely hot. The world's highest temperature was recorded on September 13, 1922, at Azezia, Tripoli, about 25° N. latitude. This station in the Sahara Desert suffered a temperature of 136.4° F.

On the whole, the Antarctic appears to be colder than the Arctic, at any rate on the continent. This is easily understood when we remember that the North Pole is covered with sea, and the Antarctic continent rises at the South Pole to a high ice-covered surface thousands of feet above sea level. At sea level, in the neighborhood of Little America the most extreme temperatures never approached the extremes of Siberia, where -56° F. represents the minimum to be expected for any winter. However, in winter on the Antarctic mountain tops the extremes of Siberia are probably exceeded, and for equal latitudes Antarctic temperatures are about 20 de-

grees lower than Arctic temperatures, above 78° latitude N and S, making the necessary allowance for the dates of corresponding seasons.

Whereas in the Arctic, bird, mammalian, and marine life extend as far north as there is open water, in the Antarctic the interior of the continent is entirely without life, for the very good reason that no life can be supported on only ice. Only about the borders of Antarctica is bird and mammalian life fairly abundant—penguins flourish, and seals and whales of many varieties are found in the surrounding seas.

HOW MAN FIGHTS COLD

During December, 1938, Britain had a spell during which the temperature averaged 27° F., or 5° below freezing. At this time the temperature in Moscow was -20° F., or 46 degrees lower than that of Britain. In such places as Moscow everyone is prepared for the cold—boots are made of felt, and fur coats and hats are common even among comparatively poor people. By law apartment houses have to be heated from November 1st to April 1st every year—not only the rooms but the staircases also. Then, too, the windows are double and everyone buys putty to fill in all the cracks. The doors fit tightly and are covered with felt; if they were not they would show a layer of frost even on the inside. Some streets have special large-scale heating systems to combat the cold, steam from a central station coming through pipes, like the gas, to warm several blocks of houses.

In the United States and Canada, perhaps the largest area in the world occupied by a large, progressive, and prosperous people, central heating

systems for large institutions, and for cities are commonplace. Ordinarily industrial, institutional, and public utility power plants furnish heat to the buildings. Modern cities underground are a network of gas and water pipes, electric power, electric telegraph, and telephone cables, tunnels for transferring heat, and tunnels or subways of various sizes for freight and passenger transportation.

The cost of heating is so high that great progress of late years has been made in the development of building materials which are themselves good insulators, and in the manufacture and installation of insulating sheetings, lining, and fillings. Even older buildings, once very expensive to heat, are now insulated at moderate cost, if one takes into account the great

saving of heating expense effected by proper insulation.

The lowest temperature ever recorded in the United States occurred in Yellowstone National Park on February 9, 1933, when the thermometer recorded -66° F. The all-time low for the continent of North America is -82° F., registered at Allakaket, Alaska. These temperatures are, of course, extremes, for the lowest recording taken in New York City in recent years was -14° F.

Fig. 14 shows diagrammatically some of the temperatures we have mentioned, and also some other extreme temperatures.

THE NORTHWEST PASSAGE

Expeditions to the polar regions have long held a peculiar fascination



Johns-Manville Co.

Fig. 13. Modern insulation with fireproof "rock wool," made from rock, solves the twin problems of keeping the house warm in the winter and cool in the summer.

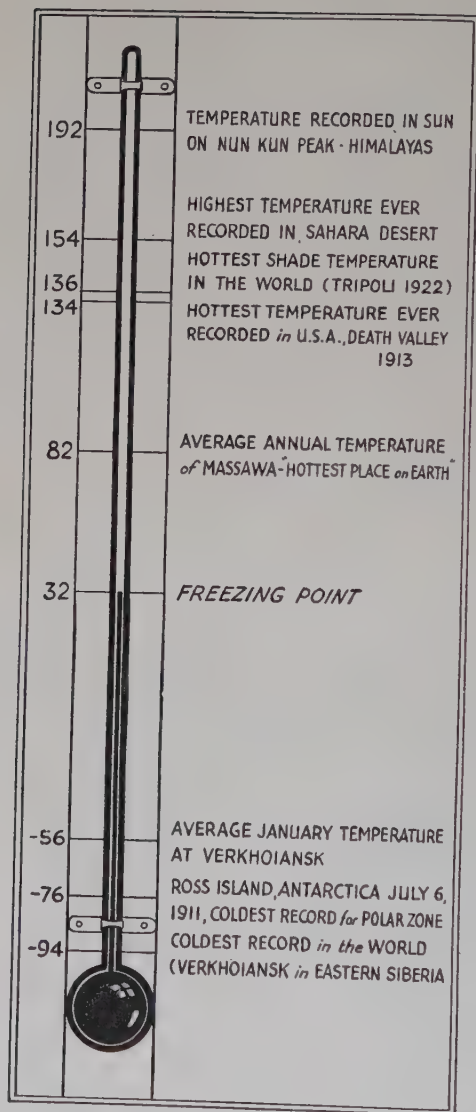


Fig. 14. Contrasts in temperature. The world's hottest and coldest places

for explorers. As early as 1497 John Cabot tried to discover a Northwest Passage around America to India.

In 1850 McClure, in attempting to discover the fate of the Franklin Expedition, found a passage through to

the Pacific, and named it Prince of Wales Strait. He was imprisoned in the ice at Melville Sound and was rescued by McClintock. Actually the voyage through the Northwest Passage was not made until comparatively recent years (1903-05), when the redoubtable Roald Amundsen sailed through in his small ship, "Gjoa," in a voyage that took three years to accomplish. Similarly, the Northeast Passage, along the northern coasts of Europe and Asia to the Pacific, was not actually navigated until 1879, when the Swedish explorer Nordenskjöld made his successful voyage.

The names of those who have carried out important explorations in the Arctic regions are familiar to all of us—Frobisher, Davis, Bylot, and Baffin were among the earliest, to be followed by Ross and Parry in 1818, and the unfortunate Franklin in 1845, to learn whose fate Ross, in 1848, McClure, in 1850, McClintock, and others voyaged to these regions. Then came Nares, in 1875, and Greely, in 1881, who reached "furthest north" ($83^{\circ} 24'$), only to be eclipsed by Nansen, in 1888, who approached to within 260 miles of the North Pole. In 1906 Commander R. E. Peary of the United States Navy reached 60 miles nearer, and three years later had the honor of being the first man to reach the North Pole, on April 6, 1909.

A year previous to Peary's achievement, the late Dr. F. A. Cook claimed to have reached the Pole by sledging alone with two Eskimos. His achievement was not officially recognized for lack of proper evidence, and Dr. Cook never challenged the decision. Since then, many explorers have flown over the North Pole, and it was in one

such flight that the great explorer Roald Amundsen perished, in 1928.

EXPLORING THE ANTARCTIC

Exploration in the Antarctic wastes has always been more difficult than in the Arctic. Whereas travelers in the north are able to replenish their food supplies from time to time from the seals, fish, musk oxen, caribou, and other animals that live there, those in the Antarctic have not had this advantage and have had to carry all their food. The discoveries of Ross (1839-43) seemed to show that the Antarctic was an impenetrable waste of ice, swept by storms of a violence unexampled elsewhere, and presenting to the open sea a wall of ice, ranging in height from 50 to 250 feet above the sea. The first Antarctic explorer was Pierre Bouvet, a French naval officer, who attempted to find the "south land" in 1739. In 1774 Cook

passed the 70th parallel, reaching $71^{\circ} 10'$, and Ross, in 1842, penetrated the ice pack and reached $78^{\circ} 10'$. He found further progress barred by a huge wall of ice, which he called the Great Ice Barrier, and sailed eastward along it for 450 miles vainly looking for an opening.

Actually he was looking at the huge cap of ice that covers the whole of the South Polar region. This ice cap has at times been variously estimated to be between 10 and 20 miles thick, but investigations into the properties of ice and the relations of its melting and freezing point to temperature and pressure, have suggested that such a thickness is impossible. Captain Scott estimated that it is probably on an average about 700 feet thick. It is assumed that the ice cap rests on rock the temperature of which is only half a degree below freezing point. If this is so, then the greatest thickness of



Fig. 15. Amundsen's tent at the South Pole. Scott's party reached the Pole on January 17, 1912, only to find that Amundsen had managed to forestall them by a month, for he had reached it on December 14, 1911

ice probably would not exceed 1,600 to 1,800 feet, only a little more than the greatest thickness that has actually been observed in the Great Ice Barrier, supposing that the bottom of the ice is not grounded on the sea bottom.

THE GREAT ICE BARRIER

This great perpendicular wall of ice is probably 1,500 feet thick, rising some 200 feet above and sinking some 1,300 feet below the level of the sea. It moves like a huge glacier at a rate of about 120 feet a month near the sea. When it reaches the sea, and is pushed out into deep water, large masses are broken off and form characteristic, flat-topped icebergs. Captain Scott, who reached an altitude of 9,000 feet at a distance of 142 miles from the Great Barrier, formed the opinion that the Ice Cap was once of much greater extent, in the Great Ice Age being probably 1,000 feet thicker than it is today.

In 1899, C. E. Borchgrevink, a Norwegian, spent the winter on the mainland of the Antarctic continent, being the first person to do so. Three years later Captain R. F. Scott, of the British Royal Navy, reached latitude $82^{\circ} 17'$, about 463 miles from the South Pole, but after suffering great privations was forced to retrace his steps. In 1909, Lieutenant Ernest Shackleton, again of the British Navy, decreased the distance to 97 miles, when failure of supplies necessitated a retreat. It was left to the Norwegian, Captain Roald Amundsen, to win the race for the coveted honor, by reaching the Pole on December 14, 1911. This was just a month before the British expedition, under Scott, reached the same goal, each expedition having approached the Pole at

the same time but from different directions (Fig. 15).

Since 1911, great progress has been made in determining the general configuration of the Antarctic continent, and in perfecting methods of research, travel, and residence. The three expeditions of Commander Richard E. Byrd have been especially fruitful. On his second expedition, in 1929, Byrd, together with Bernt Balchen, Captain A. C. McKinley, and Harold June, successfully flew their plane, the "Floyd Bennett," over the Pole.

EFFECTS OF EXTREME COLD

The extreme cold encountered by Arctic and Antarctic explorers, and those who live in such places as Siberia, has several curious effects. From them we learn that temperatures far below those that man was meant to bear affect many parts of the body, with unexpected results. If you wink for a few seconds your eye "glues up." If you have a beard you frequently cannot open your mouth, because the moisture in your breath freezes together the strands of beard on your upper and lower jaws. If you put out your tongue it freezes to your lip. If you put up your hand to "blow hot" and release your tongue, your hand freezes to your face. If you take off your glove your hand will freeze, and if you plunge the hand into water to thaw it, it will freeze the water instead. If you put a piece of metal to your flesh it will make a wound resembling a burn.

Of recent years we have read a good deal about the utilization of the Arctic as a source of human food supply. One of the main exponents of the usefulness of the Arctic has been the famous Arctic explorer, Vilhjalmur Stefansson. Stefansson has pointed

out that the enormous area of the Arctic and sub-Arctic lands of Canada might support very many more reindeer than the total of wild caribou now found there.

The introduction of reindeer, and Laplanders as herdsmen, has resulted in a very successful addition to the food and skin supply of Alaska. It remains to be seen, however, whether or not the introduction of reindeer will enable the native Eskimos either to increase materially their own standard of living or to add measurably to the exports of their territory.

It is supposed also that a larger number of edible seals might be supported, that whale might be used more widely for food than at present. Many of us know that during the last war a considerable amount of whale meat was canned and put on the market. The use of whale meat, however, as human food was not popular, although it was certainly quite edible. The musk ox as human food is, of course, much too rank in flavor to appeal to the taste of people who are used to the flesh of domesticated cattle.

Quite aside from whether or not such food appeals to the taste of a white man, the practicability of using the Arctic as a provider of meat food is questionable. The caribou range over enormous areas in great herds; it is well known that they travel fast, far, and by different routes. Famine among the Arctic peoples has often been due to the failure of the caribou to turn up in the summer time when they were expected.

John Hornby, the so-called "Snowman," and his companions in the Thelon game sanctuary starved to death in 1927 waiting for the caribou to come. The caribou had been there

other years but did not come that year, although they came back in new thousands in 1929.

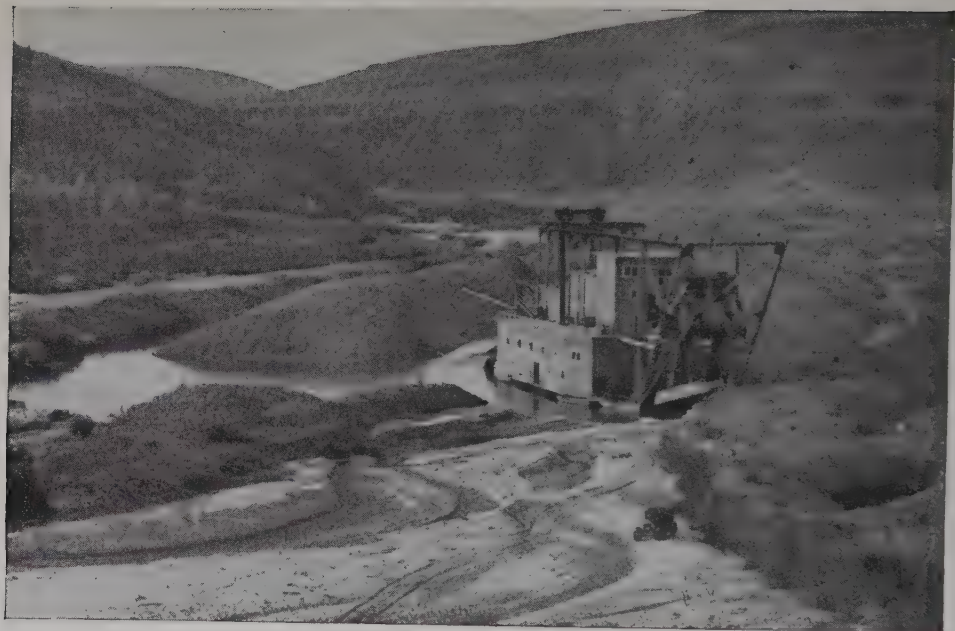
EXPLAINING CARIBOU BEHAVIOR

The explanation of the biologists for the behavior of the caribou sounds quite logical. The caribou live on lichens, because in the Arctic barren lands there are very few grasses, no trees or shrubs, few mosses, and practically no vegetation except the lichens. The caribou crop the lichens right down to the stones on which they grow. The growth of lichens is so extremely slow that after a caribou herd has browsed over a district it takes approximately eight years for the lichens to grow large enough once again to support a migrant herd of caribou.

Therefore, when one works out the area which can support one caribou on lichens, it must then be multiplied by eight if the support of caribou is to be continuous. It follows that very large areas are required to support a relatively small number of caribou herds. If any system of herding caribou were to be worked out, the herdsmen would have to be prepared to keep up with the migration of the caribou, which takes place at the full gallop whenever the food supply is exhausted.

One of the general principles which the biologists believe is that in a state of nature a wilderness generally supports about the maximum quantity of animal life which can be well supported, and they believe that any large increase of animal population in the Arctic without a corresponding increase in the plant food is doomed to failure.

The mineral wealth of the Arctic is, of course, entirely different. Min-



Copyright Black Star

Fig. 16. Huge gold dredges like this one are used to take the wealth out of the Arctic earth. Sluice dredging of this sort is often seriously impeded by the freezing of the ground from which the ore is taken

eral wealth can be taken from the Arctic almost as well as from any other part of the earth. The problems of working conditions, under modern controls, are no longer very serious.

The problem of economic transportation is, of course, always serious in the Arctic. Marine transportation has to be strictly seasonal and is always, at the best, hazardous. Aerial navigation similarly is hazardous and expensive. It, too, is seasonal in that in the winter airplanes must land with skis and in the summer with pontoons. Freightng with dog teams is very satisfactory in the wintertime, provided that the freight is sufficiently valuable to pay for the cost. The tremendously rich radium and silver ore from Great Slave Lake has paid for the cost of transportation even at many hundred

dollars a ton from Great Slave Lake to the nearest railroad, either by airplane or by dog team.

Coal was mined for a considerable time at Spitzbergen, and in case of adequate demand is still available for future exploitation. Greenland supplies practically the world's demand for cryolite, a mineral essential in the electrical smelting of aluminum. The Klondike and the Yukon, of course, have been famous for the production of gold, and the Kennicott copper mine of Alaska has produced in large quantities for many years.

THE BARREN ANTARCTIC

No mineral deposits to compare with the Arctic have yet been discovered in the Antarctic rocks, but the rock exposures are much smaller and

much more inaccessible than they are in the Arctic. At the present time the economic resources of the continental Antarctic are practically nothing, and although the economic resources of the Arctic are much greater, they, too, are obviously limited.

There has been considerable interest in the possibility of using the Arctic countries as a short route of travel from northern Europe to America, but the hazards and inconveniences under present conditions have prevented any general usage.

Compared with the tragic hardships of Franklin, Scott, and many other gallant men, the Arctic and Antarctic explorations of recent times have greatly reduced the suffering and chances of catastrophe. Expeditions equipped with radio communications, with airplanes, and with the possibility of rescue by airplane in case of need, have met the inherent dangers of such explorations and made them much less formidable. Even when equipped with motor fuel and snow sledges, Antarctic explorers and scientific workers still have difficulties and dangers enough. However,

modern aids of this kind greatly increase the effectiveness of Antarctic and Arctic scientific study.

In the final analysis one does not do such work merely for glory, nor for the thrill of the big game hunting which may be found in the Arctic. The purposes are much more worthy. The expeditions fundamentally are concerned with studies of climate and the everlasting riddles of the weather. The key to the weather of the southern hemisphere, and the means of predicting it, lie probably in the uninhabited spaces of the earth south of latitude 50°. The weather of North America and northwestern Europe—which controls the destiny of millions of dollars worth of crops every year, which threatens 90 per cent of the shipping of the world, which makes or mars aerial navigation—has its basis in the climatic conditions surrounding the Arctic sea. Many problems of oceanography must await data obtainable only in the ocean basin north of 70° latitude. The only justifiable purposes of Arctic and Antarctic exploration in this day and age are humanitarian and scientific.

CHAPTER 8

THE ATMOSPHERE

THE atmosphere, or gaseous envelope that surrounds the earth, acts as a kind of blanket which helps to keep in the heat. If it were not for the atmosphere there could be no gradual dawn nor twilight, and we should be plunged into immediate daylight at sunrise and into darkness at sunset. As it is, the upper layers of the atmosphere catch the light of the sun before it is above the horizon, bending and diffusing the rays so that they enter the lower atmosphere and give us the "half-light" of dawn. In the evening the rays from the setting sun strike the upper atmosphere long after the sun itself has sunk below the horizon, so that we have twilight. On the moon, where there is no atmosphere, sunrise is immediate, and the darkness of the long lunar night is ended instantly.

At the Arctic circle where there should be only one day without the sun setting, there are actually 22 days when the sun appears above the horizon at midnight, due to the bending of the sun's light as it passes through the atmosphere. Actually the midnight sun may be seen 18° farther south than it should appear from theoretical considerations, because of the effect of the intervening atmosphere.

No one knows to what height the atmosphere actually extends, but it is well known that it rapidly becomes thinner as the height increases. At a height of about five miles above the poles, and ten miles above the equator is the stratosphere. This is a belt of air, some 25 miles deep, that forms an upper layer of the atmosphere. It

was discovered in 1897 by L. P. Teisserenc de Bort, a French meteorologist, when he sent up small balloons that carried automatically operated registering instruments. The records obtained by these means suggested that the stratosphere was a region of constant temperature—about -55°C .—although further investigations indicate that there is a slight variation within narrow limits.

Balloons and airplanes have taught us a great deal about the upper atmosphere and about the stratosphere. The first balloon was sent up in 1783 by the brothers Montgolfier in France, and many ascents were made subsequently. In 1862, two men, Glaisher and Coxwell, claimed to have reached what was then the record height of 37,000 feet—about seven miles. They nearly lost their lives in the achievement, the air being so rarefied that Glaisher became unconscious at 29,000 feet. In 1901, Dr. A. Berson and R. J. Suring reached a height of at least 34,500 feet, and in 1931 Professor Auguste Piccard and Dr. Kipfer, sealed in a spherical aluminum gondola and carrying liquid oxygen, rose to 51,775 feet (about nine and three-quarter miles). In the following year Piccard and Cosyns, in a similar balloon, reached 54,789 feet or nearly $10\frac{1}{2}$ miles. This record was beaten in 1933 by Commander Prokofiev of the Red Army, accompanied by two Soviet scientists. They reached 62,320 feet. Their achievement was eclipsed in the following year by three of their comrades, who reached 72,178 feet, but unfortunately they lost their lives

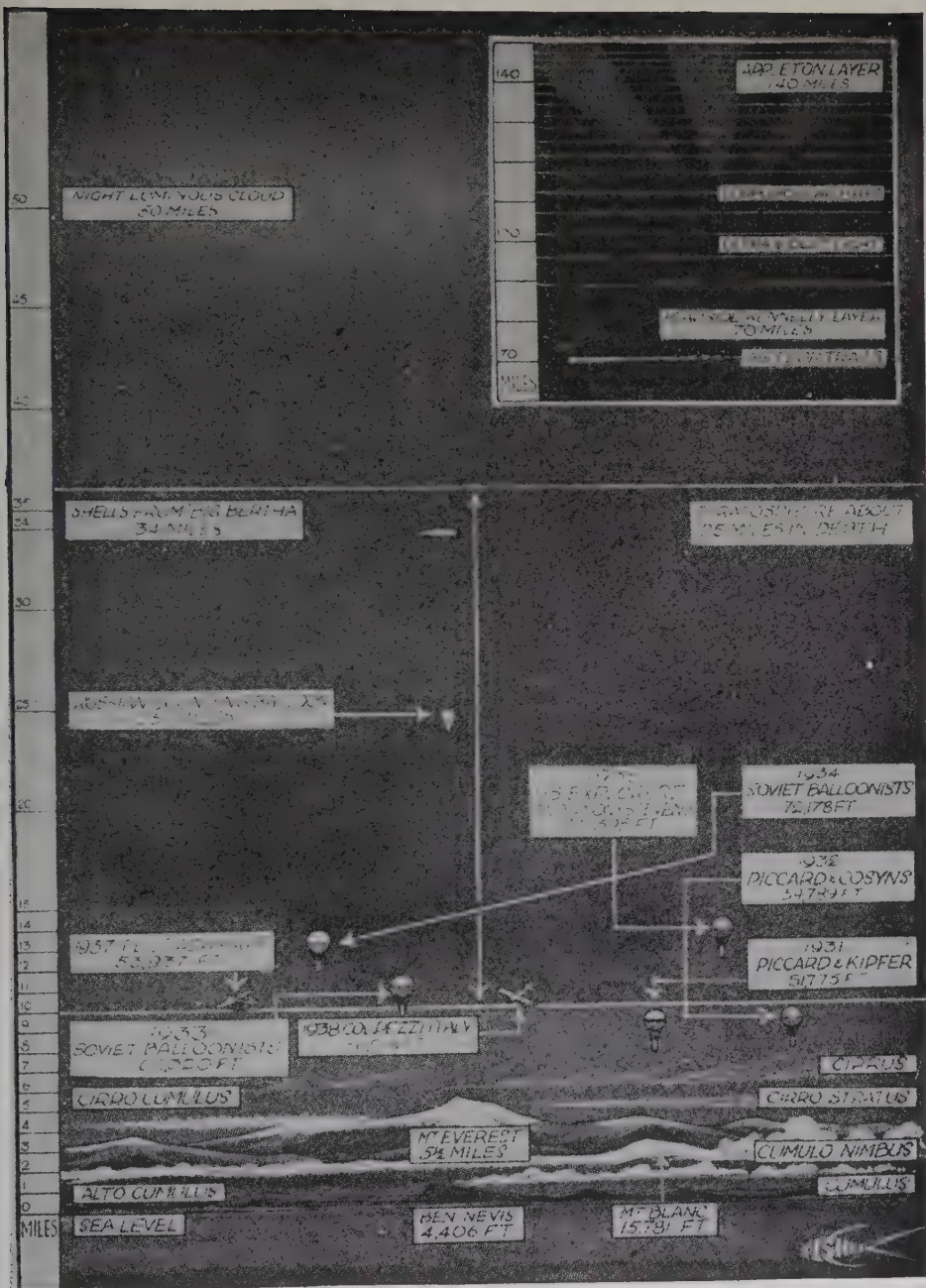


Fig. 1. The atmosphere above the earth extends to about 200 miles, becoming more and more rarefied. Men have ascended in balloons to a height of between 13 and 14 miles. Unmanned balloons have attained an altitude of about 25 miles

in the attempt. In 1935, the balloon, "Explorer II," starting from the Black Hills, South Dakota, with Captains Stevens and Anderson aboard, ascended to 72,395 feet (about 13.7 miles). These various records are all shown diagrammatically in Fig. 1.

RECORD ALTITUDE FLIGHTS

Airplanes have not been able to reach such record heights, but this is not surprising in view of the extremely rarefied atmosphere at such high altitudes. The accepted world's altitude record was set in 1938 by Colonel Mario Pezzi, an Italian. His height of 56,046 feet compares only too well with the American record of 43,165 feet, established by Lieutenant A. Soucek at Anacostia, D. C., in June, 1930. However, small, unmanned balloons, carrying recording

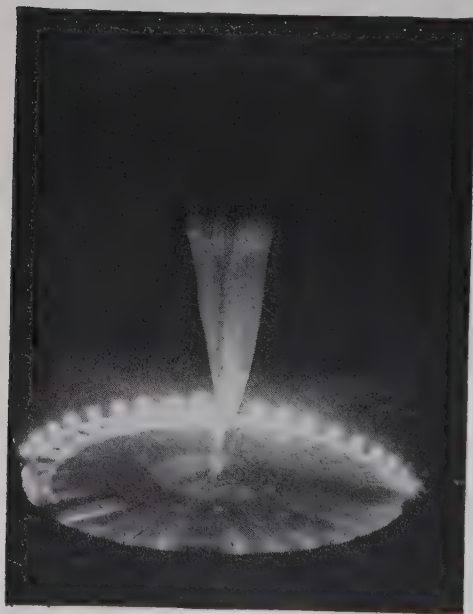
instruments, reach altitudes of about 25 miles—far greater than can be reached by man (Fig. 1).

None of these experimental flights enable us to determine the absolute limit beyond which there is positively no air. Even if we could reach greater heights, the atmosphere ultimately would be so rarefied that even the most delicate instruments would be incapable of recording any pressure.

Above the stratosphere is a peculiar atmospheric layer discovered by Lindemann and Dobson, to which we shall refer again in our section on Sound. Beyond this is the Heaviside-Kennelly layer, 70 miles above the earth. At double that height is the Appleton layer (Fig. 1). These are layers of ionized gas that act as mirrors for radio waves, reflecting them earthwards again, so that it seems impossible that we should ever be able to send radio signals to Mars or other planets. The Heaviside-Kennelly layer reflects medium radio waves and the Appleton layer the short ones. Further away in space are other "layers" that reflect radio signals at from three to thirty seconds after transmission, showing that they must be situated at about 280,000 miles and 10 times that distance respectively, as the velocity of radio waves is the same as light—186,000 miles per second.

WHAT METEORITES TELL US

Most of our knowledge as to the ultimate extent of the upper atmosphere is gained from the observation of meteorites. As we have seen in an earlier chapter, these small bodies traveling in space remain invisible until they enter our atmosphere under the combined influence of their own original velocity and the gravity of the earth. Thus, if we can ascertain



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Fig. 2. "The Explorer II," inflated and ready for Captains Stevens and Anderson to make their record-breaking 14-mile ascent

the height at which a meteorite becomes visible, we know that at that height there is still atmosphere.

To determine the height of a meteorite it is necessary to make observations from two points. Let us

has is made evident by the fact that smoke does not sink to the ground. A moment's consideration will make one realize that the smoke gas supporting the particles of dust and soot which make smoke visible, must be

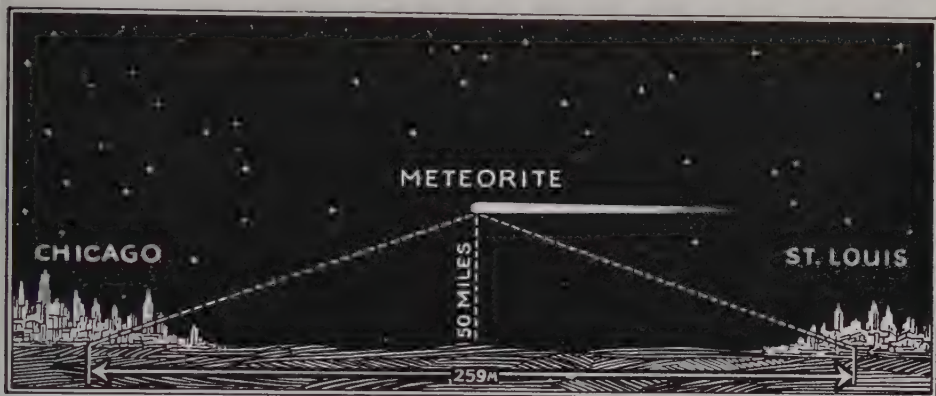


Fig. 3. How the height of a meteor is measured. The figure is explained on this page

suppose that a meteorite is simultaneously observed from Chicago and St. Louis. To each observer the meteorite appears at a certain angle above the horizon, and in a certain direction. The distance between the two observers is already known, and when the angle of altitude and direction at which each observer sees the meteorite has been also discovered, elementary trigonometry will enable us to calculate the height of the meteorite (Fig. 3). From numerous observations such as this we find that there is air of sufficient density to afford such resistance to the passage of meteorites that they become luminous as a result of friction at a height of at least 200 miles. The atmosphere extends to even greater heights in an extremely attenuated form.

WEIGHT OF THE AIR

At first thought one would not suppose that air has weight, but that it

lighter than the air through which it rises, and therefore we draw the conclusion that air must have weight.

We can prove that air has weight by weighing an electric lamp bulb on a good balance. Having done this, a hole is made in the globe with a blow-pipe to allow the entry of air to fill the vacuum. If the bulb is again weighed it will be found to weigh slightly more than before, for we are now weighing also the volume of air contained in the bulb. A similar experiment may be carried out by boiling some water in a flask. Having done this we insert an air-tight stopper. As the water has expanded by being heated, there will be a partial vacuum in the flask when the water has cooled. In this state we weigh the flask and water and having done so we then remove the stopper, allowing air to rush into the flask. If we weigh the flask again, after replacing the stopper, we shall find that it

weighs slightly more than it did before, because we are now weighing also the air that has filled the vacuum. A flask that has a capacity of one cubic foot will show a difference of one and one-quarter ounces when first weighed exhausted of air and then with air. Normally, 100 cubic inches of air weighs about two grams or seven-tenths of an ounce, or, to put it another way, one pound of air represents 13 cubic feet at standard conditions of temperature and pressure.

There is a tremendous bulk of air in the atmosphere, the comparatively light weight of which can soon become a formidable item. Even the weight of air contained in a room can be considerable, for in a room 20 feet square and 20 feet in height the air will weigh over 600 pounds. In a theater or a large hall the air may weigh as much as a hundred tons or more.

Owing to the fact that air is a fluid, the atmosphere exerts a pressure on all objects equally in all directions. This sort of pressure is like that exerted by a column of water, and it is called hydrostatic pressure. Under ordinary conditions the pressure of the atmosphere at sea level is nearly 15 pounds to the square inch. As the column of overlying atmosphere decreases as the distance from sea level increases, the pressure correspondingly decreases in intensity.

USES OF THE BAROMETER

We can make use of atmospheric pressure in several ways, as, for example, in the barometer (Greek: *baros*, weight; and *metron*, measure). This instrument enables us to measure the variations in atmospheric pressure, and, by applying our knowledge, to obtain information about probable

weather conditions. The column of mercury in a barometer is held in position by pressure of the atmosphere on one end of the tube in which it is contained (Fig. 4). Any variation in the atmospheric pressure causes an alteration in the height of the mercury, even though this variation may be only slight. An increase in atmospheric pressure causes the mercury to rise higher in the tube and a decrease in atmospheric pressure similarly causes the height of the mercury to be lowered.

As its name implies, the aneroid (fluidless) barometer, does not depend on liquid mercury but consists of a metal chamber from which the air has been exhausted (Fig. 4). Bearing on the top of the box is a steel spring capable of moving with the top of the chamber and attached to a multiplying lever that operates a spindle and pointer. The varying atmospheric pressure causes the top of the chamber to rise and fall, since, as it encloses a vacuum, there is no pressure inside to support it so that it must respond to outside pressure, and respond to relief of outside pressure by its own elasticity. Thus the pointer indicates the varying atmospheric pressure. The indicator scale is graduated to correspond with the standard mercury barometer. The indicator may be fitted with a recording pen that marks a record of the readings on a chart arranged on a drum revolved by clockwork (Fig. 5).

The barometer is often used as an aid in forecasting the weather. Many other weather conditions are dependent upon or related to differences in barometric pressure from place to place. For instance, wind is the movement of great masses of air from places of high pressure to low pres-

sure areas. The wind may be expected to blow until the difference of pressure has been equalized by the movement of the air masses. However, in the northern temperate zone we have atmospheric conditions which usually keep these areas of high and low pressure in operation for several days in succession. In other words, these differences of pressure are constantly

renewed in spite of the movement of the air which tends to destroy them.

PRESSURE AREAS

Areas of high pressure and areas of low pressure, known respectively as highs and lows, move in the northern hemisphere from west to east around the polar circle at a rate of from 500 to 1,000 miles a day. The areas of re-

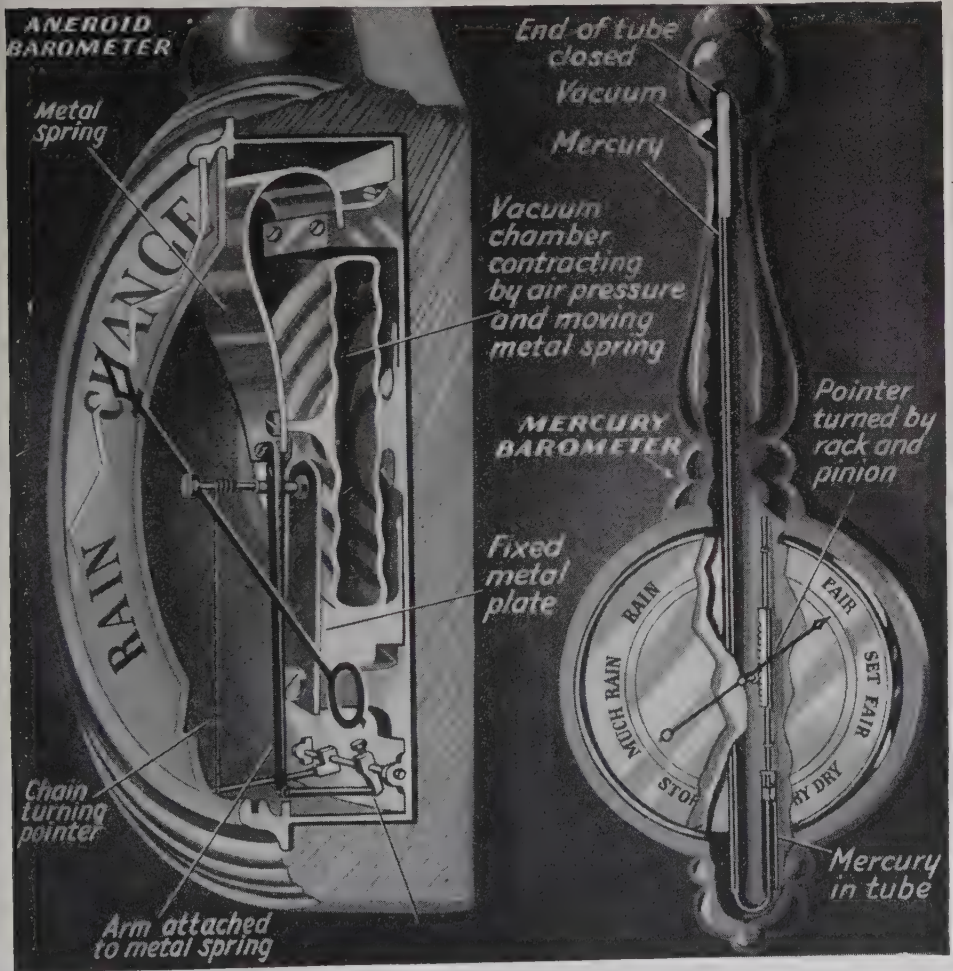


Fig. 4. (Left) Aneroid barometer, cut away to show its internal arrangement. (Right) Mercury barometer showing how a change in air pressure acts on a column of mercury, so moving the pointer. The pointer of the aneroid is moved by the contractions and expansions of a vacuum chamber

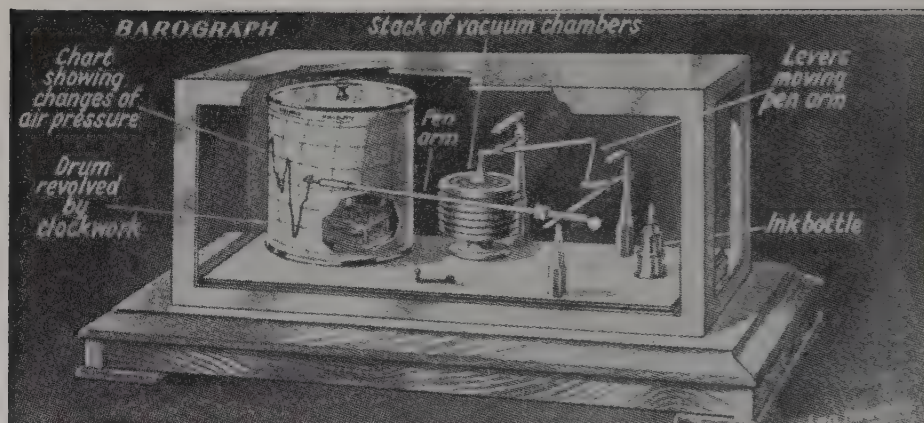


Fig. 5. The Barograph or recording barometer, which works on the same principle as an ordinary aneroid barometer. The expansions and contractions of the vacuum chambers operate a pen which records the degrees of pressure variation on a chart

sulting winds shift their position together with the migration of the highs and lows. Consequently, we usually know, if we are in a high pressure area, that a low pressure area is approaching us. How soon it will reach us we can usually guess by watching the change of the barometer. A high is usually dry and cool, or cold, a low is usually warm and rainy. A high is a place where cool air from the upper atmosphere sinks and spreads out sideways at the earth's surface, streaming off fastest in the direction of the nearest low. At a low the air tends to rise, to leave the warm earth surface and to enter the upper atmosphere. In rising it leaves regions of relatively high atmospheric pressure and becomes less compressed. Expansion of a gas causes it to cool. Thus at lows the air is cooled both by expansion and by rising to colder levels.

Chilling of the air naturally causes it to precipitate some of the water vapor it has evaporated at the earth's surface. In a desert such precipitation cannot be much, but over an area of moderate climate, or over the sea, it

is bound to be considerable. Thus we expect highs to be fair and cool, and lows to be wet and warm. This is a very elementary and incomplete story of why a falling barometer indicates rain and rising temperature, and why a rising barometer indicates, or accompanies, fair and cooler weather.

In our own times, of course, by the use of telegraphic reports from a large number of stations, it is possible to make a map which indicates the state of the weather all over the United States, and enables government forecasters accurately to foretell the weather for any place at least twenty-four hours in advance. In spite of the notorious dissatisfaction of everybody about every kind of weather, the fact remains that the United States Weather Bureau predicts our weather, such as it is, with a very high degree of accuracy (Fig. 6).

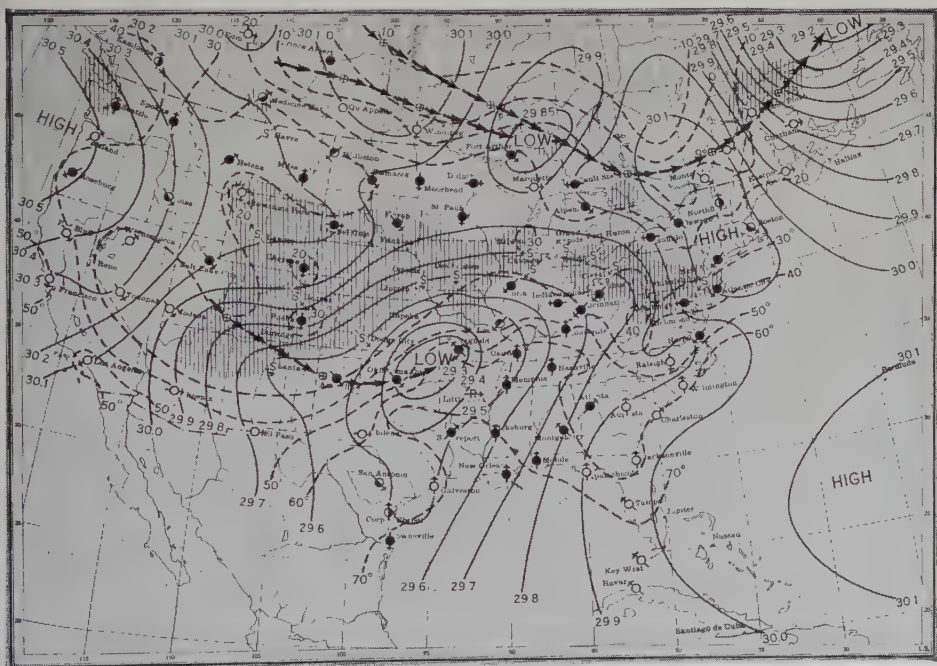
IMPORTANCE OF OXYGEN

We have explained that with an increase in height the air becomes more rarefied. Piccard and the other explorers of the stratosphere, as well

as the high-altitude airplane pilots, found it necessary to inhale oxygen from special breathing apparatus. Similarly, oxygen was used in the final stages by the expeditions that have attempted to conquer Mount Everest, the world's highest mountain, which rises to 29,002 feet. The existence of all life depends on this odorless and colorless gas, whether on land or in the sea. So sensitive are our organs and senses to the presence of oxygen that under special conditions they show a response to a difference as minute as 0.107 per cent in the quantity present. Thus the absence of the necessary amount of oxygen has a deleterious effect on the human system, and to combat this effect additional supplies are inhaled by aeronauts from suitable apparatus.

Oxygen and nitrogen in the approximate ratios of 21 to 79 volumes are the main constituents of the atmosphere. Oxygen is the active agent and is diluted by the nitrogen, its activity being thus decreased. There are also present in the atmosphere: water vapor, small quantities of other gases, including carbon dioxide—the devitalized air that is exhaled in breathing, or which is produced by combustion—and also large quantities of dust.

Dust plays a very important part in atmospheric phenomena and to a great extent is responsible for the blue of the sky. The light rays are scattered by the fine dust particles, and as the short blue rays are scattered more than the long red rays, the sky appears blue. If one were able to look along the beam of light to its origin



U.S. Weather Bureau

Fig. 6. A weather map showing the high and low pressure areas and wind directions is published daily by the U.S. Weather Bureau

it would appear golden. At dawn or sunset various colors appear around the sun. Due to the scattering effects of dust and the refraction of the atmosphere the sun appears red, but the sun's rays passing through the atmosphere above the head of the observer appears blue or green. Due to the prevalence of yellow in the sun the green shades are less commonly visible than is blue. The transmitted rays have the complementary color of the scattered rays. Sometimes very brilliant green color shows near the setting sun, fading into deep blue at the zenith.

Without the presence of these fine dust particles the sky would appear black and the stars would be visible in daylight. Counts have been made of the dust particles contained in air taken from different places. Air from above the Indian Ocean was found to contain 7,600 particles to the cubic inch, while over the Atlantic the number of particles was found to be 30,000. Generally speaking, over land the particles have been found to be more numerous and counts have resulted in as many as 60,000 per cubic inch.

IMPURITIES IN THE ATMOSPHERE

Dust may remain suspended in the air for long periods and will travel over considerable distances. Dust from Africa has fallen on vessels in the Atlantic, having traveled 1,000 miles or more after being raised high into the air by one of the prevailing hot winds that blow from the Sahara Desert. Sometimes the dust particles are so minute that they may remain suspended in the atmosphere for months or even years, before they finally settle to earth. After the eruption of Krakatoa, to which we have

already referred, volcanic dust was driven into the upper atmosphere to a height of 20 miles. Here it was caught by air currents and carried around the earth, making a circuit in 13 days. In some places it caused the sun to appear blue and the moon green. Wonderful sunsets were seen for several months, the particles of dust being of sufficient density to refract and scatter the rays of the setting sun, causing marvelous color effects. Not until two years later did the dust particles finally settle.

Dust and moisture in the atmosphere to a large extent determine visibility (the distance over which we are able to see). If the air is clear and dry, visibility will be good and objects may be seen at great distances. For instance, the lights on the top of the mountains in Corsica have been seen from the southern coast of France, a distance of 168 miles. In California, lights reflected from mirrors on Mount Shasta were seen from Mount Helena, 192 miles distant, which is a record for long-distance vision. Long-distance photographs taken at an altitude of 23,000 feet, with film sensitive to infrared rays, show Mount Shasta from a distance of 331 miles (see Chapter 6, Fig. 6).

WIND MOVEMENTS

Our atmosphere is seldom still—storms, winds, breezes, and zephyrs illustrating its constant movement. The more violent movements are due to large-scale movements of air from one region to another. These movements take place because of local differences in atmospheric pressure, nearly all of which depend fundamentally upon differences of temperature in different parts of the earth at the same time.

The heat received from the sun in equatorial regions is much more intense than that received in the polar areas. The heat loss due to radiation from the earth's surface, however, is essentially the same for all parts of the earth; consequently the polar regions are much colder than others. They would be still colder, however, were it not for the heat added by warm currents of sea and air from lower latitudes.

The movements of these currents are complicated by the rotation of the earth; otherwise there would be a constant and regular circulation of the air as it passes from the equator to the poles. As it is, however, there are some uniform changes of temperature that cause regular winds, the existence of which has been known for a long time.

The force of the wind may be registered by the anemometer, and from the record so obtained the velocity may be calculated. An anemometer may consist of four metal cups, or half-spheres, mounted horizontally on a vertical rod, and made to rotate at speeds that vary with the force of the wind. By suitable gearing from the base of the vertical rod, a dial indicates the rate of travel of wind passing the cups. In a more elaborate form of instrument the information is recorded by a pen on a paper strip fastened to a rotating drum, as in the barograph, or recording barometer. In this case the pressure and suction effects of the wind are made to act on a float contained in a closed vessel, to which is attached a light spindle that carries the recording pen (Fig. 7). The effects of pressure and suction are converted into a uniform scale of velocity, the resulting record showing each "gust" and each "lull."

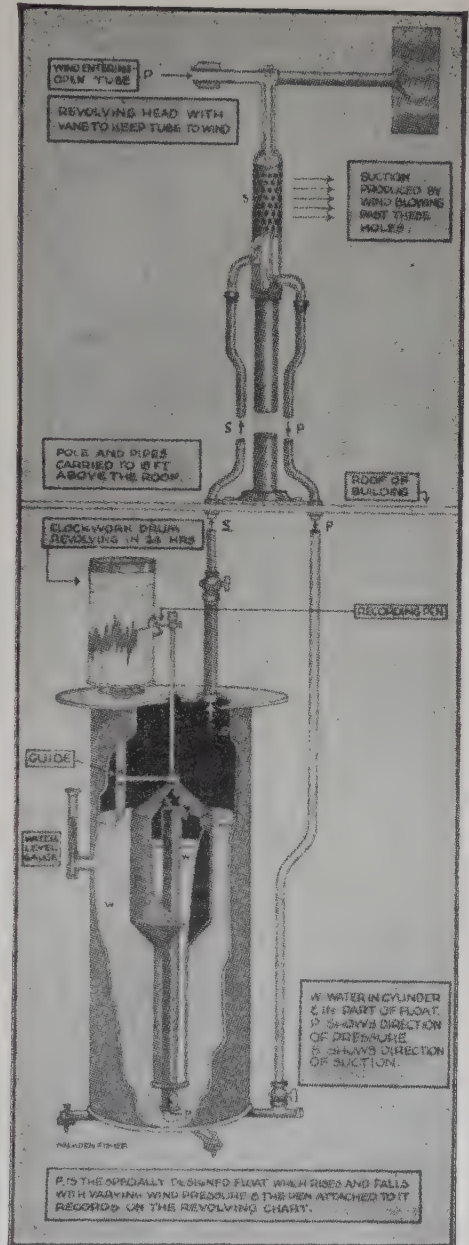


Fig. 7. Showing the workings of an anemometer, by which the force of the wind is registered, thus enabling the velocity to be calculated. This instrument gives very accurate recordings

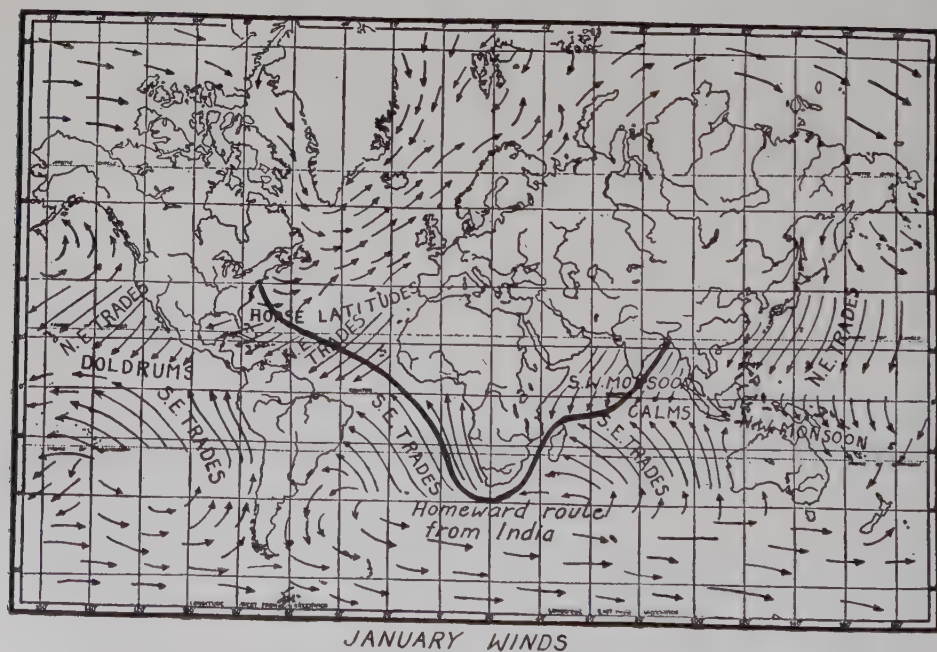


Fig. 8. Principal wind zones of the world and the prevailing air currents used by sailing ships

Ordinary winds have a velocity of less than 20 miles per hour. We think the wind is strong when it blows more than 30 miles an hour. Sixty miles per hour makes walking difficult, and any wind over 75 miles an hour is destructive.

THE BEAUFORT WIND-SCALE

The force of the wind is expressed by what is known as the Beaufort Scale, because it was devised by Sir F. Beaufort. The scale ranges from 1-12, and although it makes no reference to the velocity of the wind, attempts have been made to correlate the two factors. In 1906 the British Meteorological Office adopted the following scale:

<i>Beaufort Scale</i>	<i>Description</i>	<i>Velocity in miles per hour</i>
0	Calm	Under 2
1-3	Light breeze to gentle wind	2-12
4-5	Moderate to fresh wind	13-23
6-7	Strong wind to moderate gale	24-37
8-9	Fresh to strong gale	38-55
10-11	Whole gale to storm	56-75
12	Hurricane	Over 75

In each hemisphere there are three well-defined wind-zones. One is formed by the flow from the polar regions; another by that from the equatorial regions; and a third by those that blow from west to east (Fig. 8). In some regions there are long periods of calm—such as near the tropics, and at the equator. In the equatorial region of calm, known as the “doldrums,” the old sailing ships were often becalmed, sometimes for weeks at a time.

The constant heat at the equator keeps the air warm and always rising, its place being taken by the cooler

air from the temperate zones. As a result, the winds within the tropics blow steadily all the year round, the breeze being strongest in the mornings and evenings. These winds enabled Columbus to sail across the Atlantic, and Magellan to sail across the Pacific.

The regular winds which blow towards the equator all around the world are known as the “trade winds.” They were essential to the East India trade in the days of sailing ships. Other winds are known locally by special names. In the northern part of the Adriatic and at the western shores of the Black Sea, terrible, cold winter winds sweep down from the Alpine highlands with furious violence. It is

said that the noise of the wind drowns the sound of firearms, overturns vehicles, and causes the loss of life not only of draft animals but of the drivers as well. Between Spain and Genoa, the northern coast lands of the Gulf of Lyons know the so-called “Mistral.” This is another wild cold wind, rushing over the sunny southlands from the Alpine snowfields; it is piercingly cold, but usually dry and free of cloudiness.

From Alberta to Colorado we have the so-called Chinook winds which dry up the snow, greatly relieving the low winter temperatures, and bring

to the severe high plains of North America a modulating influence. In the Gulf states the "Norther" begins as a raw, violent, gusty wind. After the wind storm subsides, the temperature nearly always falls sharply, often to the stage of killing frosts. In Argentina a hot summer wind blows from the northern forest lands, bringing conditions of moist, sultry weather which usually promotes the spread of disease. These winds of the pampas are locally called "Zorda."

Hot winds, such as the "simoon" or "sand storm" of Africa and Arabia, are caused by the intense heat of summer—sometimes sufficient to heat the sand to 200° F. This causes the air to expand and rise, thus starting winds which sweep along fine sand that almost suffocates man and beast. A very similar wind, the "sirocco" of southern Italy, rises in the Sahara but is somewhat tempered by passing over the Mediterranean. The "harmattan" of Cape Verde and the coast of Guinea dries up every drop of moisture in its path until it reaches the sea.

WHAT ARE THE MONSOONS

Monsoons occur in the Indian Ocean and the China Sea, and navigators from a very early period have taken advantage of them to make quick passages. They blow with great force and regularity in the Mozambique Channel, along the east coast of Africa, over the northern Indian Ocean, the Gulf of Aden, Arabian Sea, and Bay of Bengal. In the Indian Ocean a northeast monsoon blows in winter, and a southwest monsoon in summer. Monsoons are a development of the trade winds and are due to the intense heat of the plains of India, Persia, and Arabia in May and June. This causes an intensified at-

mospheric low in the region which normally is a zone of highs. This results in a local reversal in direction of the trade winds. The usually accepted law governing the direction of a wind in the northern hemisphere is as follows: stand with the major low on your left and the high to your right, and the wind will blow in the direction you are facing. Thus when a low is over Arabia the wind tends to blow around the low, on the southeast side blowing in a northeast direction. The sea route is in this quarter, and consequently "the Monsoon" wind of the sailors blows northeast. Other seasonal winds north of Australia, and in the China Seas are also called monsoons, but those of the Indian Ocean are usually thought of as "the Monsoons."

Tropical cyclones and tornadoes (Fig. 9) are more intensive than monsoons—they are more local in character and of a temporary nature, and may better be described as revolving windstorms. They occur in the Indian Ocean and in the Pacific and China Seas, where they are called typhoons. The West Indies know them as hurricanes or whirlwinds, and in Australia the same kind of storm is called the "willy-willy." These revolving storms may cause enormous damage.

A hurricane that struck the West Indies in 1851 traveled a distance of 2,500 miles, destroying much valuable property and causing the deaths of 1,477 persons. Houses were razed to the ground and ships torn from their anchorages and cast ashore. At Calcutta, in 1804, a typhoon resulted in over 60,000 people losing their lives, the destruction of numerous towns, and the loss of over 100 ships. Three years later another typhoon resulted in the deaths of 90,000 people and

the destruction of 30,000 houses in Lower Bengal as well as a considerable amount of shipping. Another tropical cyclone, a typical Caribbean hurricane—and one of the most disastrous of modern times—occurred at British Honduras in 1931. Within half an hour of its arrival all the churches were wrecked and there was not a building undamaged. A 200-ton dredger was lifted bodily out of the sea and dropped on the roof of the Customs House some way back from the shore.

The storm was followed by a mountainous wave that threw ships and barges high and dry upon land. Then came a fire that completed the work of destruction.

ATLANTIC COAST HURRICANES

These tropical cyclones are related to the hurricanes that occasionally sweep the Atlantic coast of the United States. One of the most recent of these storms—that of September 21, 1938 (Fig. 10)—caused enormous devastation and ruin over a great area in the New England states. Often communications were destroyed, so that knowledge of the plight of the stricken inhabitants and speedy assistance for them were alike delayed. Whole sections of towns were devastated, and large tracts

of land were flooded. This hurricane was the worst that our Atlantic seaboard has known for more than half a century.

The New England coast lies west of the usual track of these hurricanes, most of which originate near the equator, sweep through the West Indies and swing northeastward into the open Atlantic somewhere between eastern Cuba and Florida. In some



Fig. 9. A tornado passing over David City, Nebraska. It traveled a few miles doing great damage, then disappeared into the sky



Copyright Black Star

Fig. 10. The hurricane which blew into New England in September, 1938, played all sorts of queer—and expensive—tricks. Among them was one played on the good ship "Nellie," which was left high and dry at the railroad station

cases, however, the hurricane path continues east to the Florida or Texas coast. A particularly severe storm caused the great flood of Galveston in 1900. Storm waves swept over the city, destroying property to the value of about 25 million dollars and causing the death of nearly 6,000 persons. A similar hurricane wrecked large sections of Florida in 1935. The storm swept away large sections of the famous railroad which extended from island to island on miles of causeways to Key West. The storm caused property damage amounting to many millions of dollars and cost many lives. In general hurricanes reach the southern Atlantic coast once in several years, although in most cases the damage is likely to be trifling.

These cyclonic hurricanes are most frequent about September. In 1936 one of them swept the coast of the Carolinas and Virginia, driving thousands from their homes and flooding dozens of towns. Some attempt has been made to arrange a system of hurricane warnings in the United States, but such warnings can only enable people to get into places of relative safety. Too little is known of the causes of hurricanes to permit long-range forecasting. Why they are much more frequent and violent in some years than in others is still quite unknown.

NATURE OF A TORNADO

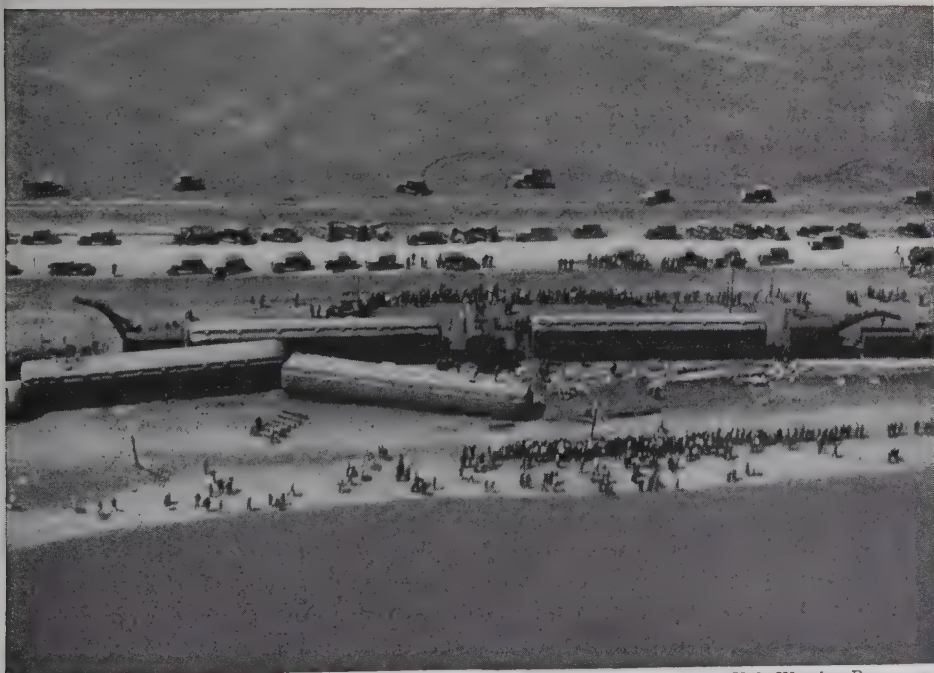
A tornado is a vortex, or funnel of wind, reaching high up into the air.

It is more local than either a hurricane or a common cyclonic storm, and may cut a path 30 miles in length but perhaps only 1,000 feet in width. The path of a tornado is so narrow and so well-defined that people frequently escape by running out of it. At the center of the vortex is a partial vacuum, the effect of which is to cause the atmospheric pressure inside buildings to blow outwards the roof and the walls, so that the result is virtually an explosion inside the house. Some curious phenomena are seen during a tornado. Straws have been driven into trees and timber fences as though they were steel rods. During a tornado at Calcutta a bamboo cane was driven through a mud

wall six feet thick and lined on each side by a course of bricks.

Although a tornado seldom lasts for more than an hour, and for not more than a minute or so at any one place, its destructive effect is very great. It seems to make up in increased violence for the shortness of its duration. Houses may be lifted from their foundations, wagons hurled through the air, and people, animals, and wreckage, carried for considerable distances. In 1931 a tornado in North Dakota wrecked one of the fastest and most luxurious trains on the Great Northern Railroad, lifting the whole train off the track (Fig. 11).

Tornadoes move at speeds of a hundred miles an hour or more, and occa-



U.S. Weather Bureau

Fig. 11. These railway coaches of the "Empire Builder," a Seattle to Chicago train, were blown from the track by the force of the wind about five miles east of Moorhead, Minnesota, on May 27, 1931. This aerial view was taken after the wrecker had replaced two of the coaches on the track

sionally attain enormous velocities of several hundred miles an hour. They cover an area of from twenty to some hundreds of miles and are generally preceded by oppressive heat, followed by a short period of ominous calm. Then the leading edge of the storm approaches and strikes with tremendous force; this is followed by a period of comparative calm, after which the following edge of the storm arrives, the force of the wind then being in the opposite direction.

THE CAUSE OF TORNADOES

Tornadoes are probably caused by eddies formed by two masses of air moving in opposite directions at high speed or by two masses moving in the same direction at different velocities. The modern concept of the atmosphere pictures it as a composite body made up of masses of air of different temperatures, specific humidity, and consequently of varying specific gravity. A large mass of cold air usually caps the polar areas. This is somewhat less mobile in behavior, and rotates about the earth's axis less slowly than a belt of warmer air at lower latitudes.

There is commonly a sharp surface of separation between these two masses, which meet at a surface which usually stands at a low angle with the surface of the earth. This surface is called the polar front. Whenever this polar front pushes unusually far south, so that there is a considerable contrast in the energy content of the atmosphere on either side of this surface, then there is likelihood of tornadoes. On one side the warm air moves much more rapidly than the cold air on the northern side, the plane of separation persists until some of the air, dragging past the

polar front, whirls itself into eddies. If these eddies go very fast and represent warm air which rises rapidly in contact with the cold polar front, then a tornado comes into being. It may be moderate in development and harmless, or it may be extremely violent.

A similar occurrence taking place over the sea results in a water spout, the reduced pressure at the vortex sucking up water from the ocean and apparently drawing water from the clouds. The two cones of water, both in rapid rotation around their centers, meet; at the same time the water-spout travels across the sea in a direct line. Waterspouts vary in diameter from two to 200 feet, and may extend to heights of 1,500 feet or more, moving at from walking pace to 4,000 feet a minute. Strange as it may seem, there have not been many instances of damage to shipping by waterspouts, although five small vessels were once sunk in the harbor at Tunis. Waterspouts over land seem to have been responsible for more destruction; in 1856 a 1,500 foot waterspout near Calcutta covered half a square mile with water to a depth of six inches.

EFFECT OF DUST IN THE AIR

We have already referred to the large amount of dust particles suspended in the atmosphere. These dust particles help to cause fog, for the water vapor in the atmosphere condenses on them because gas molecules are commonly occluded by surfaces of solids. Once a layer of water vapor thus condenses, the drop formed adheres to the dust particle by virtue of the surface tension of the liquid. Each dust particle becomes the nucleus of a globule of

moisture, perhaps .01 inches in diameter, that falls to earth only slowly, the attraction of gravity being almost balanced by the friction of the air through which it passes. These globules carry minute electrical charges and these cause them to repel one another, so that they do not coalesce to form drops of water. Further condensation of water vapor on the globules may cause them to grow larger, however, when they sink through the air more quickly. Should they be subjected to the heat of the sun's rays the moisture is turned to vapor again and the fog is dissipated.

Fog is not always caused by dust, but may be due to drifts of moisture-

laden air meeting drifts of cold air. This occurs notably off the coast of Newfoundland, where there are almost perpetual banks of fog caused by warm air from the Gulf Stream meeting cold air from Labrador and the Arctic.

Similarly, along the western coasts and in New England, the foggy weather prevalent at certain seasons is due to the moist air from the sea blowing over the colder land surfaces. The fogs of the North Atlantic conceal icebergs which have already taken a ghastly toll of lives and ships. This has given rise to the so-called "Iceberg patrol" of American Atlantic waters, conducted by the United

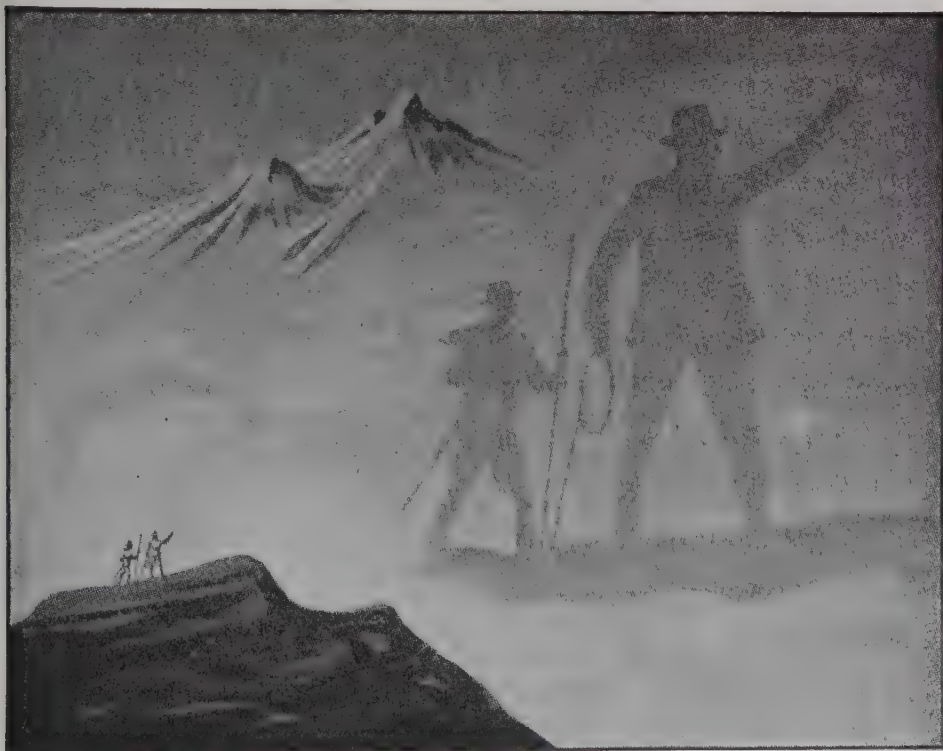


Fig. 12. The Specter of the Brocken, seen in the Harz Mountains. This once caused great terror to the inhabitants, but the phenomenon has a simple explanation. The so-called "specter" is the shadow of observers thrown on a bank of mist

States Navy in co-operation with the Canadian and British Governments. Since the establishment of the Iceberg patrol there has been no major disaster due to ships striking the fog-shrouded icebergs.

The "Specter of the Brocken" is one of the striking effects of mist (Fig. 12). The Brocken is one of the highest of the Harz Mountains, and here is seen the curious effect to which the mountain has given its name. Actually the "specter" is the shadow of the observers thrown on a bank of mist that rises from the valley, the appearance being that of a ghostly image of men of colossal dimensions, dark as a whole but bounded by a colored outline. To the superstitious peasants of the region the appearance was ascribed to a huge demon who inhabited the mountains, striding from peak to peak with supernatural ease.

Similar "specters" are to be seen in other parts of the world, wherever there is a convenient screen of mist and when the lighting is from the appropriate quarter. Balloonists sometimes see a somewhat similar effect, the enlarged image of the balloon surrounded by luminous rings being projected on to the clouds below, while they themselves are in bright sunshine. Aviators, too, see these "anthe-lions" when flying over a sea of cloud, a luminous circle exhibiting all the colors of the rainbow—for it is indeed a complete rainbow. In the center of the circle the aviator sees a shadow-image of his airplane.

WHAT CAUSES CLOUDS

The condensation of the water vapor in the atmosphere by which fog and mist are formed accounts also for the formation of clouds, which may be

regarded as accumulations of mist at a high altitude above the earth. The amount of moisture that can be held as vapor in the atmosphere depends on the temperature, for air at high temperature will hold more water than when at low temperature. As a gas, water vapor is, of course, invisible, but should the temperature fall below the critical point, the molecules draw together and form drops of liquid. This is called condensation and is the opposite of evaporation.

When the atmosphere is carrying so much water vapor that only a slight lowering of the temperature will cause condensation, it is said to be at saturation point. At a temperature of 32° F. air can contain $\frac{1}{160}$ part of its own weight in the state of vapor. With every 27° increase in the temperature the amount is doubled, so that at 59° F. it can contain $\frac{1}{80}$, and at 86°, $\frac{1}{40}$ of its own weight. It is easy to understand that actually there may be more water vapor in the atmosphere in the summer than in the winter, for the temperature then is higher. The degree to which air is saturated with water vapor at current temperature is generally called its "relative humidity," or in more modern terminology its "specific" humidity.

When the atmosphere is saturated with water vapor it condenses even if the temperature be lowered only slightly, and the molecules form droplets of water so small that they have been appropriately called "water dust." This may occur when saturated warm air ascends to a higher altitude where the temperature is lower. When this occurs the condensation of the water vapor forms a mass of innumerable droplets, and this we call a cloud. Should the cloud of moisture



Fig. 13. The Matterhorn, showing the famous "Cloud-banner" that hangs from the peak like smoke from a chimney. This banner is nearly always to be seen

again come in contact with a current of warm dry air the droplets are converted back to water vapor. Thus we

can easily understand why the clouds are ever-changing, for the water is continually being changed from liquid

to gas. Not only is this due to the alternating currents of air but also to the fact that the droplets themselves slowly sink by the action of gravity, eventually reaching a layer of air that is of a sufficiently high temperature to evaporate them.

MATTERHORN CLOUD-BANNER

These constant changes cause interesting phenomena to occur on the tops of some mountains that are peculiarly situated. On the Matterhorn we have the "cloud-banner," a streamer of cloud apparently clinging tenaciously to the mountain and held steady for long periods, almost like smoke from a factory chimney (Fig. 13). Actually, the extremity of the "cloud-banner" is continually dissipated into the atmosphere, the banner being as quickly renewed at the other end, so that it is as though a river

of cloud is being sent up from the mountain.

This phenomenon is erroneously explained as being due to the air charged with moisture being chilled by the cold peak of the high mountain. This error is so common that it is worth the trouble of definite correction. When gas is condensed it tends to get hot. If the heat is not conducted away, or used up by performing some work, the gas must get hot. When restraint is removed, and the gas is allowed to expand, it absorbs heat again, thus becoming cold. This well-known fact is made use of in the common refrigeration systems which operate with compressed carbon dioxide or other commercial gases. Whenever moist warm air is made to expand, it cools and rapidly reaches the dew point, causing first fog and then condensation of water.



Fig. 14. The Rock of Gibraltar with the famous "Plume." This curious cloud is always to be seen over the Rock whenever the "Levanter" wind is blowing

When the sun shines on the face of a mountain like the Matterhorn, the rock absorbs the heat very rapidly, and becomes hot even at high altitudes. Consequently, rather than chilling the air about it, it actually warms the air, causing it to absorb moisture and to rise. In rising, however, it reaches levels of lower pressure and therefore expands. In expanding it cools, in cooling it precipitates or condenses some of its moisture. Hence a body of air rising up the face of a mountain, forms a cloud as soon as it emerges into the open atmosphere above the shelter of the mountain peak. Far from chilling the air, a sunny mountain top actually warms it.

A similar phenomenon occurs at the Cape of Good Hope, where Table Mountain is seen to be covered with cloud. This "spreading of the table cloth," as it is called, is due to air from the Indian Ocean, saturated with water vapor, condensing into a thick white cloud when the bulk of the mountain athwart the course of the wind forces the air to rise over it. The rising of the air causes it to cool and some of its moisture to condense. The cloud thus formed covers the flat mountain top and rolls down over the opposite side. Halfway down it meets warm air that again vaporizes the water so that the cloud does not succeed in reaching the foot of the mountain. At Gibraltar, too, the "Plume" forms over the rock when a Levanter is blowing from the east. The Rock deflects the warm air into a higher altitude where the air expands and cools, and the moisture is then condensed into cloud which streams away to the west (Fig. 14).⁴

The formation of different kinds of clouds is affected by various con-

siderations, chiefly height, temperature of the atmosphere, air currents, and the constituent particles forming the cloud. These last-mentioned may be droplets of water, as we have already explained, or in some cases they may be tiny particles of ice.

THE GROUPS OF CLOUDS

At the beginning of the last century, clouds were divided by Luke Howard, an eminent meteorologist, into three main groups, and on this scheme is based the present classification. Today ten classes of clouds are recognized and are arranged according to the altitude at which they occur. Without going into a detailed classification we may take Howard's three main groups as representative.

First, there are the cumulus clouds, generally dense and compact in appearance, having a more or less horizontal base and an average altitude of about 5,000 feet (Fig. 15). These are the clouds that look like wool packs and they accompany fine weather. Sometimes they are of enormous extent, and in most climates they attain their greatest size early in the afternoon when the day is hottest. Before rain they increase rapidly in size and appear to be lower, with their under surfaces less distinct than when the weather is fine.

The second group of clouds is the stratus, generally low-lying, flat sheets of cloud that stretch across the sky. They are generally seen near the horizon, and at sunset they present a beautiful appearance. "Weather prophets" regard them as a sure sign of fine weather when they appear at sunrise or sunset. They form so quickly that on a calm night a cloudless sky may be covered by them in less than ten minutes.



U.S. Weather Bureau

Fig. 15. The figure to the left shows cumulus clouds, a form often seen in bright clear weather. The formation to the right is that known as cumulonimbus. Such clouds produce showers of rain or snow and often thunder storms

The third group is the cirrus, delicate, white, fleecy clouds that stretch across the sky or range in parallel belts. These clouds have the least density of any, and the greatest variety of form. They float only in the upper regions of the atmosphere and generally are from five to ten miles above

the earth. It is these clouds that are composed of minute ice crystals and cause haloes around the sun and moon. Sometimes cirrus clouds may be seen extending from one horizon to the other. They may remain visible for only a few minutes or may persist for some hours. Observations



U. S. Weather Bureau

Fig. 16. Picture above shows a striking formation of altocumulus clouds

of cirrus clouds are of great value to meteorologists, giving the first indications of a coming change in the weather. When their edges become indistinct, rain may be expected soon, but when their edges are clear and well-defined, fine weather may be expected to continue.

Generally speaking, most clouds are at an altitude of over 3,000 feet and they are higher in summer than in winter. They travel across the sky at speeds that vary with their height, since at different heights the speed of the wind varies greatly. Frequently the higher clouds travel progressively faster than those at lower levels, although there is no reason why this should be a necessary relationship. Cirrus clouds at 30,000 feet have been observed traveling at 150 miles per hour; cumulus clouds at 5,300 feet at 24 miles per hour; and stratus clouds at 1,670 feet at 19 miles per hour.

WHY CLOUDS CAUSE RAIN

Everyone knows that there is a close connection between clouds and rain. We have seen that a cloud consists of droplets of moisture and that these droplets may grow in size by the increasing condensation of moisture. Although the original droplets are of small mass they have a relatively large surface, causing them to resist any tendency to sink to the earth. If the droplets are not evaporated by encountering warm air, additional condensation may cause them to increase in size. The surface is not increased in the same proportion as the mass, however, for the weight of a sphere is in proportion to its volume, which increases as the cube of the radius, whereas the surface increases as the square. The consequence is that the air can no longer

support the larger drops and these fall to earth as rain. If they fall through moist air in their descent they gather more moisture and become larger and larger, a process that accounts for the varying sizes of rain-drops.

Records of the amount of rain that falls are kept in most places by means

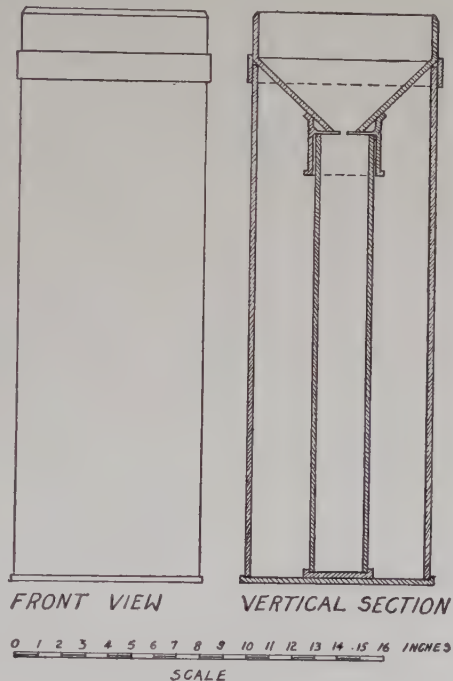


Fig. 17. Diagrammatic representation of a rain gauge

of a rain gauge. This is a simple device of a funnel and a bottle or can of uniform size, the object being to collect all the rain that falls in a given area and to store it without evaporation until it can be measured.

In the United States the Weather Bureau standard rain gauge is made of two cylinders, one inside the other. The inner cylinder has a diameter of 2.53 inches, and the outer one eight

inches. A funnel fits over the outer cylinder, and leads into the inner cylinder. The rain collects in the inner cylinder to a depth 10 times that of the actual rainfall. By measuring the depth of the water collected the actual rainfall is computed. Self-recording rain gauges have a balanced pair of small receptacles so arranged that when rainfall fills one, it tips and empties, placing the other in position to be filled. This likewise fills, tips, and puts the first cup back in position. Electrical connections record each time the gauge is filled as well as the hour of filling, thus providing a continuous self-recorded score of rainfall and speed of rainfall (Fig. 17).

Since an acre of ground contains 43,560 square feet, it is not difficult to calculate that one inch of rain over an acre will weigh 113 tons, and will consist of 27,154 gallons, or 3,630

cubic feet. In other words, a fall of one-tenth of an inch of rain is equal to about one and one-eighth tons of rain per acre.

"Mean annual rainfall" includes all the rain, snow, or hail—indeed all forms of moisture that can be measured—that falls during a year on some particular locality. As the amount of rain differs in the same locality at different times, one year may be much wetter than another.

WHERE RAINFALL IS GREATEST

Rainfall is generally heavy in the tropics, supporting the great forests of equatorial America, Africa, and Malaya. The rainfall is usually greatest in mountainous districts—and especially in those where the prevailing wind is from the sea—and is usually smallest in the interior. The reason for this is that when a moist wind blows against a mountain it is diverted to the rarer and higher levels of the atmosphere. As cool air cannot hold as much water vapor as warm air, the vapor condenses and falls as rain. On the other hand, by the time the wind has reached the opposite side of the mountain, the air has been robbed of much of its water vapor and there is less tendency to condensation and rainfall. Inland, where the temperature is more constant or increases, the moisture remains in the air as water vapor.

The same air driven beyond the mountains to lower levels, becomes warmer by compression, and actually evaporates whatever moisture it may meet. As a rule, rainfall is most concentrated in the tropical regions subject to so-called rainy seasons. These annual periods of rainfall depend upon the seasonal winds blowing from the sea to mountain uplands.



U.S. Weather Bureau

Fig. 18. Measuring the precipitation collected in a standard eight-inch rain gauge at the U.S. Weather Bureau

When the advance of the season causes the winds to change their direction for that latitude, then the wind blows from land to sea, and the rainy season gives place to the summer or dry season.

In certain places, due to special relationships between prevailing winds, the sea, and mountains, rainfall is excessive. In the valley of the Amazon the rainfall is about 700 inches a year, due primarily to the usual tropical conditions. Equally heavy rainfall in Madagascar is due, however, to seasonal winds, the monsoons. Similarly in the Khasi Hills in Assam, just south of the Himalayas, 500 inches of rain falls annually—as much rain may fall in one day as New York receives in a whole year! Among the world's other "wet spots" may be mentioned Mount Waialeale, in the Hawaiian Islands, where the average rainfall is 476 inches per annum. At Cherrapunji, Bengal, the average annual rainfall is 429 inches. Here, between January 1 and August 31, 1938, 536 inches of rain fell.

DRY PLACES OF THE EARTH

No rain at all falls for several years at a time in certain deserts. For instance, in parts of western Australia rainfall is very uncommon. It generally rains once or twice a year, but some years there is no rain altogether. After a rain, plants spring up from dormant seed, run their life cycle, drop seed, and die. Then the seed lies until the next rain—whenever that happens to be. Between rains, dust accumulates nearly everywhere. But when it rains, every rock and pebble is washed clean—at least for a little while. Then men go for a walk looking for gold. Every little nugget or speck of gold shines brightly in the

sunlight until the next windstorm covers it up. As long as the gold shines clean and bright, people go out looking for gold particles; this occupation is called "specking."

In the Gobi and Sahara Deserts reports say there are places where it has never rained in the memory of man. However, the fact that such places have long been entirely uninhabited, leaves one in doubt as to the accuracy of such reports. Certainly, however, rainfall in such places is negligible.

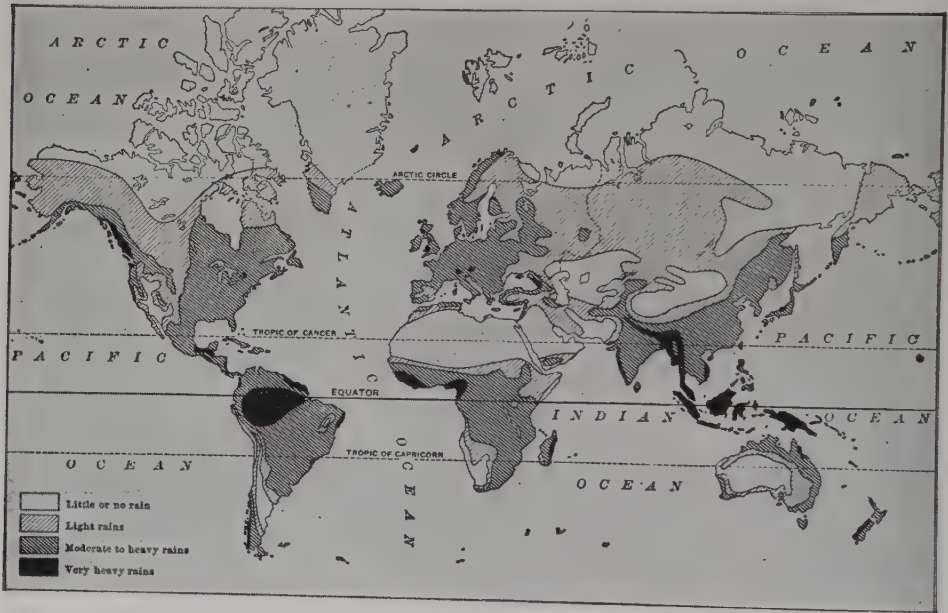
In the United States very heavy rainfall has been recorded on the western slopes of the Olympic Mountains in Washington, and on the mountain uplands of Georgia, where over 100 inches of rain a year is normal. Other parts of the country have much less rain, large areas of the Southwest and Western plains having rainfall deficient for either agricultural or grazing requirements. Very large parts of the Mississippi Valley and parts east have rainfall which is usually adequate in quantity and is suitably distributed in season. Consequently, so far as rainfall is concerned, the United States may well continue as one of the world's greatest agricultural nations.

CONSTITUENTS OF RAIN WATER

Although it generally contains some impurity—such as carbon dioxide—that it has taken up in its passage through the atmosphere, rain water is the purest of all natural waters. This is more particularly true when the rain water has been collected at places far from human habitation. It is because of its purity that rain water is so "soft." It is insipid to the taste because it does not contain the minerals in solution to which we are

accustomed in spring or well water. Absolutely pure water cannot be obtained in a natural state, nor can it be prepared in the laboratory, although samples of highly purified water have been prepared and found nearly to approach the ideal. Rain water may be purified by distillation,

fine particles from animal and vegetable waste and decay that are suspended as dust in the atmosphere. As we have already seen, it is on these particles that the water vapor in the atmosphere condenses, the ultimate raindrops bringing the organic matter back to the earth.



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Fig. 19. This map shows the mean annual rainfall of the world

and to make more certain of its purity the water obtained in this way is redistilled.

For use in making television screens, water is employed as a solvent of the activating salts. It must be pure. To make it pure it is redistilled twice in glass retorts, once in a quartz retort, to remove the traces of sodium, and finally in a retort of platinum. Thus distilled and redistilled the water is very nearly chemically pure.

Rain water contains more organic matter than well water, because of the bacteria and large quantities of

RAINFALL CURIOSITIES

Sometimes natural processes give rise to curious effects, as, for example, the shower of red rain that occurred in 1608 at Aix, when large red drops of liquid were seen on the walls of the cemetery and of the church. The inhabitants were greatly alarmed at what they regarded as a "shower of blood." The explanation probably lay in the fact that the rain had brought down with it a large number of *algae* or tiny plants. Such *algae* consist of microscopical spheres measuring less than .001 inches in diameter and belonging to the simplest forms of vege-

table life. Red rain has often been recorded subsequently, as at Vienna and in Italy in 1901, in Cornwall and Hamburg in 1902. In 1903 fine red dust from the Sahara was brought down by rain over the southern part of England.

Four showers of black rain fell in 1862 in Scotland, due probably to the presence of fine volcanic dust brought back to earth from the higher atmosphere. Yellow rain, such as fell in east Scotland in 1854, can be explained by the presence of quantities of pollen lifted by the wind and brought down by the rain. Some years ago seeds of *veronica*, or speedwell, covered the ground in south Prussia after a violent rainstorm, and seeds of ivy similarly were found in the south of England. Even this does not exhaust the marvels of rain, for on several occasions it has actually rained fish! In 1817, at Appin, in Scotland, there was a shower of small herrings, and again in 1830, at Islay, in Argyllshire, a similar phenomenon occurred. Some fifty years ago there was a shower of small frogs in the west of England, and in 1900 a similar shower occurred after a thunderstorm near Liverpool.

All "miraculous" showers of this kind have similar explanations. The herrings—be it noticed that they were small—were lifted into the clouds by a waterspout at sea; the small frogs, by a whirlwind either from a swamp or meadow. The difficulty of explaining all such rainfall curiosities involves the fact that the true origin of such peculiar deposits can seldom be proved. In many cases it may be that the deposits, as in the case of frogs, were on the ground before the rainstorm, but were not recorded until afterwards. No rainstorms bringing

either fish or frogs have been reported far from either seacoasts or swampland.

WEATHERING OF ROCKS

The atmosphere works marvels of sculpture, exceeding in grandeur and complexity anything achieved by the arts of man. In an earlier section we mentioned that although the granite rocks were formed deep down in the earth, granite may be seen at the earth's surface. In many places granite stands up in great mountains which lend themselves so well to monumental purposes that, on Stone Mountain, Georgia, and on Mount Rushmore, in the Black Hills, Gutzon Borglum has made colossal statues of some of our national heroes. The granite originally deep down in the earth has been laid bare with the removal of overlying rocks by weathering and erosion. Exactly as the formation of new rocks is going on today, so, too, is denudation, for nature is constantly at work, creating and destroying in a ceaseless cycle.

The chief agents by which denudation is carried out are frost and temperature changes, the atmosphere, and running water. Although to us these forces may appear to work very slowly, they nevertheless work with extreme sureness. There is no hurry, and the process may go on for a thousand or a million years until, in the end, the work of destruction is completed. Even in the short span of our own time we can see the effect of some of the forces of denudation in the "weathering" of the stones in old buildings or in old walls, particularly when these are composed of the less hard stones, such as brown stone, Potsdam red, and various other sandstones (Fig. 20).



Fig. 20. How the weather wears away rock. This wall has only been in position about a century

When water pipes burst in cold weather we know that water has frozen in the pipes. It is well known that water expands when it changes into ice. When water freezes in the fissures of a rock, the rock may be split open. In the course of time even the strongest rocks may be broken up by the drastic action of frost.

Further destruction is caused by the changes of temperature as between day and night. The heat of the sun's rays during the day causes the rocks to expand, but when night comes and the temperature falls they contract, and at a much greater rate than they had expanded. The result of this continual expansion and contraction is the disintegration of the rocks. Some rocks are broken up in this way more easily than others. This is true of granite, which is composed of three materials that expand at different rates.

THE AIR

However, most of the disintegration of rocks is due to chemical weathering rather than to temperature

changes alone. All the processes of the atmosphere attack exposed rock surfaces simultaneously. In the chemical effects, water itself, oxygen, and carbon dioxide are the chief agents, and against them even granite and the hard crystalline rocks cannot stand up.

The air in motion carries sand into action, the sharp grains beating against the rocks and wearing them away. Notice a glass bottle on

the seashore, how it is etched until it looks like ground glass as the sand sweeps against it. Sometimes wind-worn rocks present a remarkable appearance, due to some parts being harder than others and so resisting erosion for a longer time. In the arid regions of the Southwest are some remarkable examples of this action, where ages of erosion have brought about most fantastic shapes. Red Rock Canyon, in the Sierra Nevada, is a great gorge in which the rocks have been carved by nature into wonderful likenesses of buildings and animals.

Pillars and fluted columns, pilasters and colonades, temples and castles, cathedrals and towers and domes, rise tier after tier and mile after mile. In Bryce Canyon, Utah, are skyscrapers (Fig. 21), and in one place a gigantic natural statue of Queen Victoria (Fig. 22).

BOULDERS PRODUCED BY WEATHERING

In various parts of the world large rocks are perched upon a small base, so nicely balanced that they look easy



Fig. 21. Striking rock formations, almost skyscrapers in stone, in Bryce Canyon, National Park, Utah. These formations have all been produced by erosion



Fig. 22. This wonderful rock in Bryce Canyon bears a remarkable likeness to Queen Victoria. It is purely the result of weather erosion and is untouched by hand

to push over. Ordinarily their mass is so great that they are more solid than one might expect. They are often called "balancing rocks" because of their precarious position (Fig. 23).

In some cases these rock masses are glacial erratics, blocks deposited by a melting ice sheet. In other cases they have been made by the scaling off, or exfoliation of the surface of a massive rock, leaving large boulders or masses standing like gigantic marbles over the countryside. Such boulders of exfoliation are highly characteristic of massive granite rocks. Others are produced by wind work and allied processes of weathering which separate great blocks from the bedrock after which the exposed angles gradually wear off more rapidly than smooth surfaces. This process results finally in the wearing away of all angles, edges, and corners.

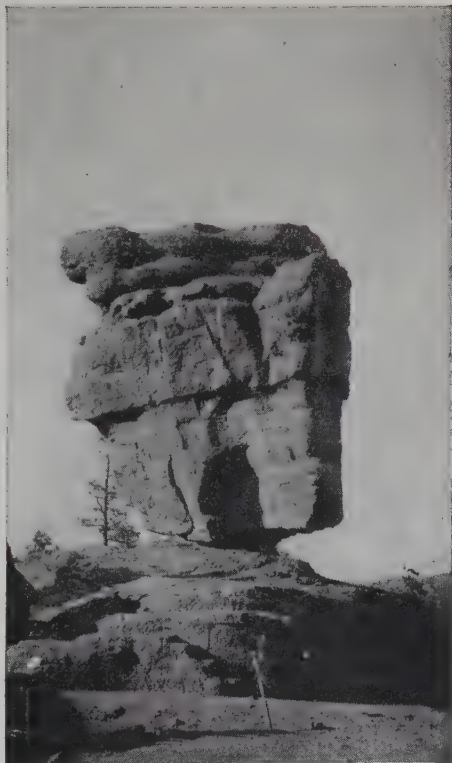
In glaciated regions we see perched boulders due to ice work; in other regions we find boulders produced by weathering. In Lands End, the southwestern tip of England, there are numerous masses of granite separated by weathering from the parent bed rock. In South Africa, under entirely different climatic conditions, we find the kopjes, or isolated hills which rise above the veldt, covered with an encumbrance of granite or other plutonic rock masses generally rounded in outline, all due to spheroidal weathering. In Yosemite Park, the great half-domes of granite which tower over the walls of the canyon, are themselves vast masses peeled off into their colossal shapes.

RAIN A CHEMICAL REAGENT

Another important agent in the work of denudation is rain. It is active largely because it has a chemical ac-

tion brought about by the presence of the gases that it takes up from the atmosphere. These gases are chiefly oxygen and carbon dioxide, the former of which brings about the chemical changes, known as oxidation, that indirectly cause the rocks to decompose. At a temperature of 60° F., water will absorb its own volume of carbon dioxide and under normal conditions of temperature and pressure, 100 volumes of water will absorb 1.48 volumes of nitrogen, 2.99 of oxygen, and 100.2 of carbon dioxide.

We see the destructive effect of rain more particularly in our towns and cities, where the rain is heavily



U. S. Geological Survey

Fig. 23. A balanced rock in the Garden of the Gods in Colorado



Fig. 24. Curiously worn rocks at Brimham, Yorkshire, in rain soaked England. The weather has eroded the overlying strata; and sand, carried by wind, has worn the rock into fantastic shapes. Here are found many likenesses to monkeys and other animals



Fig. 25. More rocks at Brimham. This well-known formation has a curious resemblance to a dancing bear

charged with impurities. Among these impurities is a relatively high concentration of carbon dioxide from the burning of gas, coal, and petroleum, which causes a rapid solution of calcium carbonate. In one city, for instance, a marble monument was found to have lost one-third of an inch over its surface in a century. Also in coal and gas there is usually a considerable percentage of sulphur, which upon burning forms sulphur dioxide, a corrosive gas, which when dissolved in water is an active reagent.

In places where copper or zinc ores are being smelted there used to be a great escape of sulphur dioxide into the air. This obnoxious gas is now carefully conserved in the smelters for the manufacture of sulphuric acid. In spite of all sorts of smoke prevention campaigns, and in spite of the modern tendency to conserve all the by-product gases of all manufacturing processes, the air over our great cities and large factory districts is badly contaminated.

HOW RAIN ATTACKS THE ROCKS

Rain also penetrates through the cracks in the rocks caused by the changes of temperature and by frost, and so speeds up the general work of destruction. An enormous, but incalculable, amount of rain water percolates through the surface of the earth and decomposes rocks at depths of 200 feet or more.

In the copper-bearing rocks of Michigan, mines have been sunk nearly a mile into the earth. From the surface to the bottom of these mines, water percolates through the rocks, and drips from all exposed rock surfaces underground. All through the intervening space from the surface of the land the constant "drip" does its deadly work, illustrating the truth of the old saying that "con-

stant dripping will in time wear away the hardest stone." Stone is not nearly so impenetrable as it seems.

If we assume—as we may reasonably do—that one-third of the rain that falls on the land is quickly evaporated, the remaining two-thirds, whether flowing into rivers or sinking into the ground, are at nature's disposal for the purposes of denudation, either by chemical or mechanical means. Literally, these are the forces that "shape" the earth.



Fig. 26. The Cheeswring on Bodmin Moor in Cornwall England, another example of spheroidal weathering. The rocks and soil have been worn away



Fig. 27. On the fifth and lowest level of Mammoth Cave, 360 feet below the surface of the earth, is Echo River. In width it varies from 20 to 60 feet, in depth from 10 to 30 feet. At flood stage this arched passage is completely filled with water

UNDERGROUND SOLUTION

Where the rock formation is suitable, this percolating water, in its work of subterranean destruction, often forms caves. The carbon dioxide in the water converts insoluble carbonates into soluble compounds, giving rise to a solution of calcium bicarbonate. The amount of calcium carbonate thus dissolved out of chalk and limestone formations is very great, resulting in large and small caves being formed in the solid rock.

Some of these caves thus formed are of considerable size. The Postumia (formerly the Adelsberg) Cavern, in the province of Trieste, Italy, and about 50 miles from the city of that

name, has a succession of caves and connecting passages extending over a distance of 14 miles, and through some of them the River Piuca, formerly the Poik, flows.

The Postumia Cavern is one of the largest in the world, and in many ways is the best known. On Whitmonday an annual ball used to be held when this cavern was in Austrian territory, in the third of the great chambers, known as the Kaiser Ferdinand Grotto. This was brilliantly lighted, and offered a scene of remarkable beauty due to the semi-translucent beauty of its stalactites and to their graceful shapes. Of special scientific interest is the Mag-



Fig. 28. Wookey Hole, a great cave in England. The river flows through the Hole into daylight near this point. This cave had been famous since 1874 when great prehistoric remains were found in it

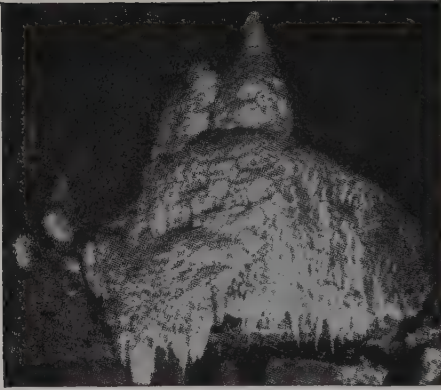


Fig. 29. A typical stalagmite—the "Wedding Cake"—in the Ruakuri cave, New Zealand

dalene Grotto because it supports a peculiar subterranean amphibian known as *proteus anguinus*. It is a sort of newt, about a foot long, which lives on worms and snails. Ordinarily life is very scanty in deep caves.

Mammoth Cave, Kentucky, is the largest cave in the world. The main cavern is 300 feet in width, 125 feet in height, and some four miles in length. There are about 150 miles of passages—most of which are inaccessible—cascades of falling water 250 feet in height, lofty domes 300 feet in height, and pits 200 feet deep (Fig. 27).

In Somerset, famous as the home of Cheddar cheese, a well-known cave, Wookey Hole, contains a subterranean pond large enough for

rowboats (Fig. 28). In the limestone country of Yorkshire are many caves and sinkholes. Sinkholes are the openings from the surface into cracks which lead into open fissures or caves. In England, Gaping Ghyell is a popular showplace. Here a large pipe extends to a depth of 210 feet and opens into the vault of an immense subterranean hall, 480 feet in length, 110 feet in width, and 100 feet in height. Here the water has excavated a reservoir of 100,000 cubic yards capacity, as well as about half a mile of galleries.

Although many such caves are known and have been thoroughly explored in many parts of the world, there must be innumerable caverns and passages that have never been

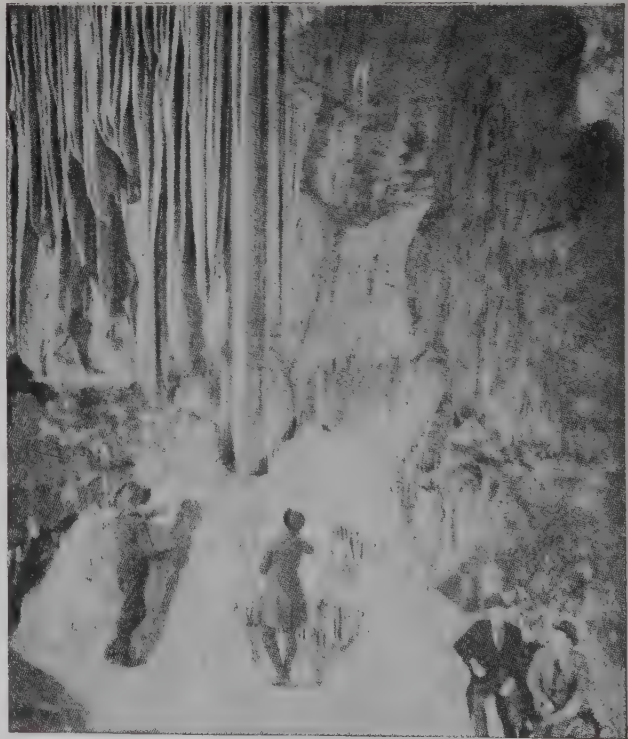


Fig. 30. The "Frozen Curtains," a number of very wonderful stalactites in the Carlsbad Caverns

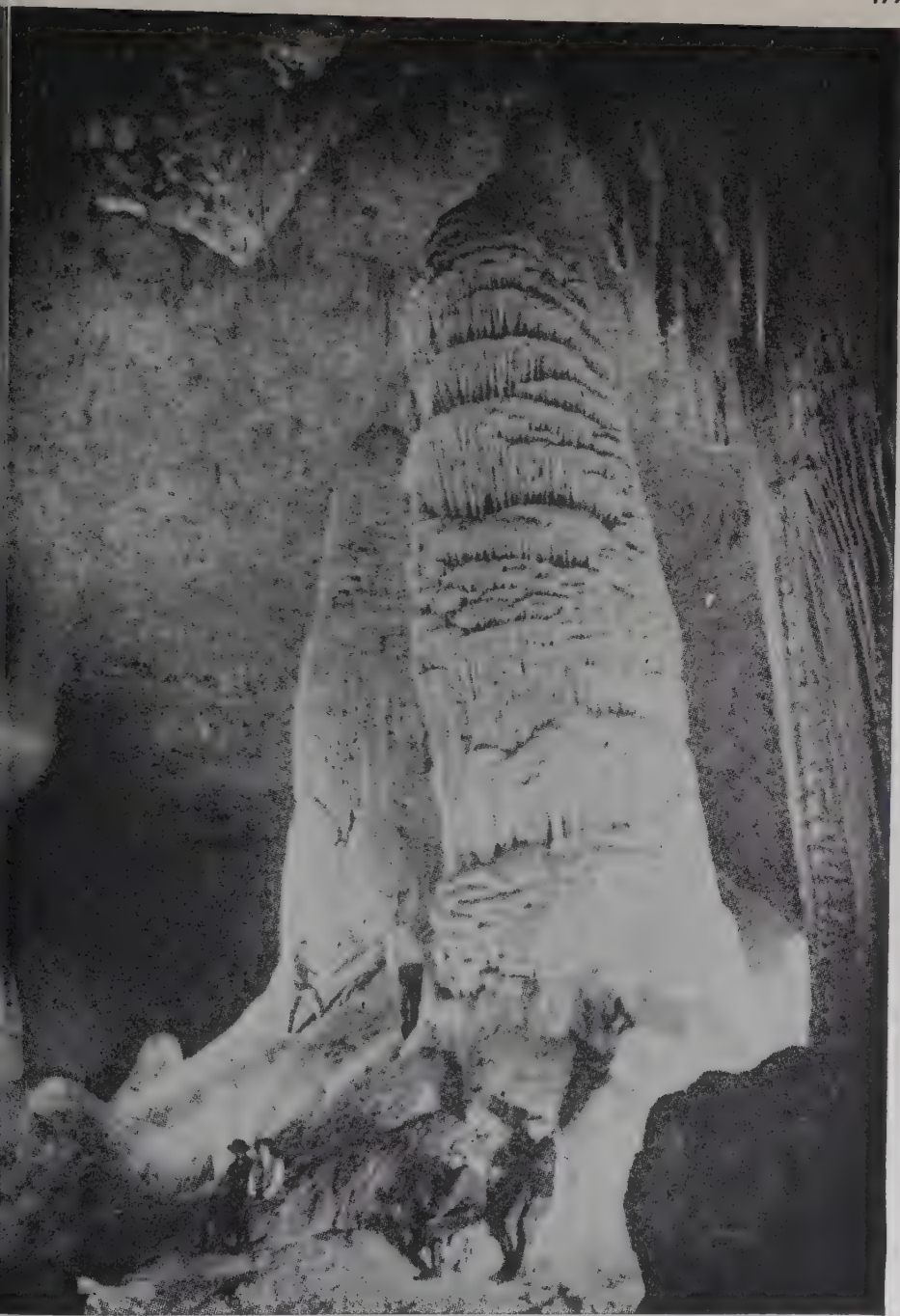


fig. 31. Huge pillars in the Carlsbad Caverns which must have taken ages to form



U.S. Soil Conservation Service

Fig. 32. This land once produced 100 bushels of corn an acre and was worth about \$100 an acre. Water erosion has removed five inches from the top of the field, and left this gaping hole in the middle of it

discovered, for everywhere the percolating water is at work, dissolving the soluble minerals and breaking down the rocks.

In most of these caves stalactites are to be seen (Fig. 30). These beautiful objects consist of a fine crystalline deposit, and are usually of a conical or cylindrical shape. They form by water percolating through the rock and becoming charged with bicarbonate of lime. This is held in solution by the free carbon dioxide gathered by the water from the air and soil. When the water reaches the roof of a cavern from which it drips, water evaporates, leaving behind it the deposit of carbonate of lime in the form of an iciclelike pendant hanging from the roof. Sometimes an excess of water drips off the end of

the stalactite on to the floor of the cavern, in which case the pendant form is reversed, and an upward-pointing pinnacle is formed. This is called a stalagmite (Fig. 29). Sometimes if the process continues long enough, the two deposits meet, and joining together form one continuous column from the floor to the roof of the cavern (Fig. 31).

SOIL EROSION

The formation of soil depends upon the weathering processes which break up the rocks into particles small enough for plant roots to use as a medium in which to grow, and from which to draw nutriment for the living plant. When the plant dies the organic matter in the roots is added to the so-called humus, or plant tissue

materials, which gives soil its porosity and its capacity to retain water. In the development of soils from rocks the atmospheric agencies are helped by ants, earthworms, burrowing animals, and plant roots, all of which help to render the soil friable and easily aerated and drained of excess moisture. Bacteria, minute organisms as they are, perform a great sum total of useful and perhaps essential services by fixing in forms available to plant life, the otherwise intractable nitrogen of the atmosphere. Bacteria illustrate as well as anything the great value of invisible influences, too small individually to be appreciable, but in combination of great importance. Frequently, many of the mysteries of nature can be explained by a microscopic analysis of the process and its agencies.

Soil erosion is generally recognized today as a menace to the permanence of agriculture in North America. Among students of the sciences its importance has long been appre-

ciated. The Mississippi River alone carries enough mineral soil materials every year to cover a square mile of land about 600 feet deep. All this comes by the work of surface waters, and by the solution achieved by rainfall.

Farmers have long been neglecting to prevent the spread of gullies by headward erosion. Little has been done to prevent the top soil from being blown away from corn and wheat lands in dry seasons. All this material swept away by wind and rainwash leaves the upland never to return, except by the very slow process of geological weathering agencies. We see here in the processes of weathering and erosion, a sort of check and balance between the destruction of old rocks, the building up of new soil, and the erosion of the old soil. As one or the other process gains under cultivation, man himself either becomes rich or he endures such hardship and poverty that he must migrate or perish.

CHAPTER 9

WATER IN ALL ITS FORMS

IN the previous pages we have learned a good deal about water, and we may profitably pause to consider what water is and how it is formed, since it is not an element.

An element is one of the ultimate forms of matter that cannot itself be split into anything more simple. Any element (with the exception of argon) will combine with one or more other elements to form a compound. Thus everything is either an element or a compound. Actually, an element consists of a number of atoms of the same kind, but a chemical compound consists of atoms of at least two kinds. Countless compounds occurring in nature can be reproduced in the laboratory, while thousands of compounds can be produced artificially that do not occur in nature.

Oxygen and hydrogen are elements—that is to say, nothing but oxygen can be obtained from oxygen, and nothing but hydrogen from hydrogen. Water, on the other hand, is a compound of the two, and by analysis can be resolved into oxygen and hydrogen atoms. This was not discovered until after Cavendish, Volta, Humboldt, Gay-Lussac, Lavoisier, and other scientists had expended years of patient labor. It was Joseph Priestley, the discoverer of oxygen, who in 1781 found that the explosion of oxygen and hydrogen in a closed tube produced water. He thus proved that water was not an element, as had been supposed up to that time, but a compound of the two gases. Oxygen is 16 times as heavy as hydrogen, atom for atom, and the propor-

tion by weight in water (which is composed of 2 hydrogen atoms to every 1 oxygen atom) is 16 of oxygen and 2 of hydrogen, or 8 to 1.

Let us now explain how we obtain the chemical formula H_2O for water. When atoms combine to form compounds they always do so in definite proportions by weight that are characteristic of the compound. The atomic weights of each of the 92 elements are known and each, therefore, is placed in its correct position in the table of elements. This commences with No. 1, hydrogen, the lightest element (atomic weight 1.008), and runs to No. 92, uranium (atomic weight 238.10). Thus, as the atomic weight of hydrogen is 1, and that of oxygen 16, the symbol H means one part by weight of hydrogen and the symbol O means 16 parts by weight of oxygen. The expression of the composition of water by the formula H_2O , therefore, means that it is composed of hydrogen and oxygen, that 18 parts by weight of the compound are composed of 2 parts by weight of hydrogen and 16 of oxygen.

CONSTITUENTS OF AIR

Air consists of gaseous elements mixed but not combined, each element retaining its peculiar characteristics. Water, consisting as it does of two gaseous elements, displays the properties of neither. We may measure out into a test tube the requisite proportions of the two gases, but they form only an invisible gaseous mixture. This mixture does not possess any of the properties of water, al-

though the tube contains in correct proportion all that is necessary for the production of water. If an electric spark be made to occur in the tube, the gases will disappear and in their place will be found a drop or two of water. If desired, this water can be decomposed into the mixture of the two gases as before.

When a compound is resolved into its constituents, the process is called analysis. The opposite process—the building up of a compound from its constituents—is termed synthesis. Synthetic dyes, for instance, are those built up in the laboratory, as distinct from substances that are natural dyes. It is interesting to learn that the discovery of the composition of water was made not by analytical processes but by synthetical—that is to say, by putting the constituents together in conditions in which they would combine to build up the compound.

THE PROPERTIES OF WATER

Water is colorless, tasteless, and odorless. It is a powerful reflector of light and a bad conductor of heat and electricity. It is totally unlike either of the gases of which it is composed, being neither a supporter of combustion like oxygen, nor combustible like hydrogen. It is, of course, of the greatest importance to mankind, and a glance at any map will show that nearly all important towns and cities are situated on some body of water. In most cases this arises from the fact that the towns of today occupy the same sites as did the settlements of prehistoric man. These were often made near a river, where there was a plentiful supply of fresh water. At the water side they had the protection of the open water, on one side at least, against predatory animals and

human enemies; they found fish for food; and they had a means of travel by raft or canoe. All rivers, of course, are built up by the discharge of their tributaries, and the small tributaries are each drainage systems in themselves, for they are supplied from seepages and springs.

We have already seen that a great amount of the rain that falls percolates into the earth. Exactly how deep the water percolates depends, of course, on the nature of the ground. Those rocks—such as clay—that refuse to allow water to soak through are said to be impermeable, although sometimes an impermeable rock may allow a quantity of water to pass because it is fissured with cracks. Others—such as limestone and sandstone—are known as permeable, because although apparently hard and durable, they are sufficiently porous to allow water to pass through the interstices, or little spaces, that are left between their individual particles. Although some such rocks may appear to be sufficiently close-grained to withstand the passage of water, they do in fact absorb it, as is often evident from the fact that stone freshly quarried generally holds a quantity of water known as “quarry water.”

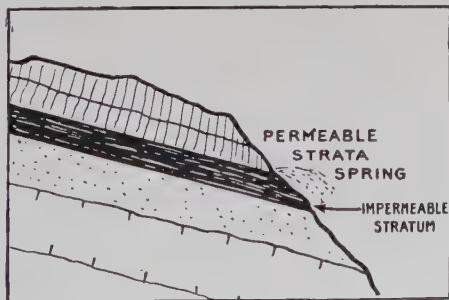


Fig. 1. How a surface spring comes to the surface on the side of a hill

THE WATER TABLE

All this water that is absorbed by the rocks continues to sink through the underlying strata until eventually it reaches an impermeable stratum, or until it reaches a place below which the rocks are already completely saturated with water, and can absorb no more. This is as far as the water can go; the level below which the rocks are saturated is known as the water table.

It may be that the strata are inclined at an angle—due to earth movements—in which case the water that has percolated through from the rocks above will flow along the impervious stratum. In high lands, rain falling on the hilltops may sink into such a porous bed; and wherever this layer outcrops on the hillside at a lower level water will escape as a spring or seepage (Fig. 1). Such springs are to be seen by anyone who looks for them along the bases of valley walls of large streams, and at the upper end of many little brooks which trickle out of the hills.

Should the impervious stratum not reach the surface, the percolating water continues on its way down to-

wards the water table. During its passage in areas of limestone, as we have already seen, the water may drip through caverns, collecting into underground streams which work downward towards the lowest level they can reach. Wells driven into these rocks, which are partly or completely saturated with water, may be used to draw out great quantities of well-filtered, unpolluted water. Many large towns are supplied with water at least in part by means of wells. Until relatively modern times all northern European and American cities relied for water supply upon rivers, lakes, and wells. The ancients used aqueducts to bring water into their great cities, and most modern great cities can no longer be supplied by local wells but must, like the ancients, bring in their water supplies from distant hills or lakes.

The main disadvantage of wells for the water supply of great cities is their lack of capacity. They have, however, a further disadvantage—the water from underground sources is usually very “hard” due to dissolved minerals.

Paris is one large city which draws water from wells. Deep down under



Fig. 2. A sectional drawing illustrating the seepage of water into a porous layer beneath the surface of the earth. The water follows the slope of the hills, and comes forth as springs on the lower levels.

Paris—about 1,600 feet—is a supply of good water, believed to originate at Mont Blanc, and capable of supplying 200,000 gallons a minute if required.

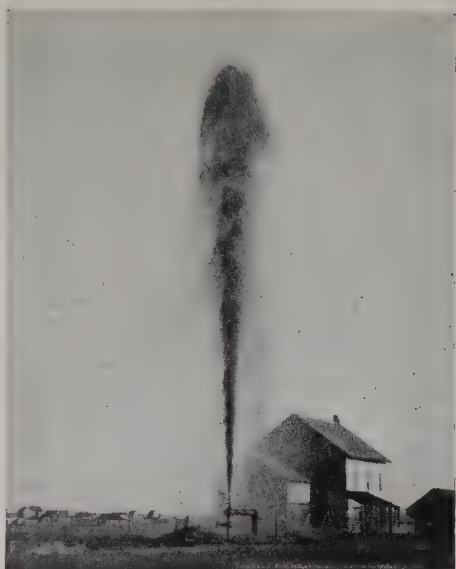
Below London the rocks are bent into the shape of a basin, which is a great natural reservoir. Water from the Chiltern Hills and the North Downs, north and south of London respectively, flows underground along the tilted layers of porous chalk beds. The rain that falls on the chalk hills, sinks into the ground and replenishes the underground supplies. It is prevented from sinking lower than the chalk bed by an underlying layer of clay that is impervious to water.

Under London itself is a bed of clay that prevents the rain that falls on London from reaching the chalk, so that the rain runs off the surface of the impermeable clay. By sinking wells through the London clay, however, the great natural reservoir can be tapped.

ARTESIAN WELLS

A well that supplies water to the surface under enough pressure to make the water flow freely, without need of pumping, is an artesian well. Such wells cannot be made simply by drilling or digging deep wells anywhere. Geologic conditions of a definite type are a prerequisite.

Berlin, in Germany, and St. Louis and Pittsburgh, in this country, get artesian water at a depth of about 4,000 feet. In large areas of North and South Dakota flowing wells about 1,000 feet deep provide the only adequate local water supply. Along the Atlantic coast hundreds of thousands of people depend upon artesian wells for their domestic water supply. In this case the wells are ordinarily



U.S. Geological Survey

Fig. 3. An artesian well with water escaping at Woonsocket, South Dakota

rather shallow, from 100 to 300 feet deep. At St. Augustine, in Florida, a very large well, 1,400 feet deep, furnishes 10,000 gallons a day. At Silver Springs, also in Florida, the water gushes out at the surface without the need of any well or other artificial outlet.

The principle of the artesian well is not difficult to understand.

In a liquid that is at rest the pressure is uniform over all points in a horizontal plane, even though the liquid may not extend to the same depth over the containing vessel. This statement may be expressed in another way by saying that a liquid always finds its own level. If a number of glass vessels of various shapes and sizes are connected to a tank, and if liquid is poured through any one of them until the tank is more than filled, the level the liquid attains will be the

same in each vessel, even if the tank is tilted at an angle. An important application of this principle is that of the artesian well. A well is sunk through the ground to an underground water supply. Up the well-shaft the water finds its own level (Fig. 2). If this is not at a convenient height, the water is brought the rest of the way to the surface by pumping.

UNUSUAL SPRINGS

Some springs come to the surface beneath the sea, and may be seen around the coasts at low tide (Fig. 2). In England there is a large spring that comes up in Dover Harbor. Near the Gulf of Spezia, in Italy, fresh water mingles with the sea. The population of Bahrein in the Persian Gulf depends on the fresh water that it obtains from the sea. Boatmen dive to the sea bed with water-skins at a known spot and bring the supplies ashore. These particular submarine springs probably originate in the hills of Oman, 500 miles distant.

Some springs are intermittent, discharging water for a time and then ceasing. Some springs in Europe are known to have discharged irregularly at intervals for many centuries, and their activities have been regarded as portents of battles, famines, and plagues. At Giggleswick, in England, is a remarkable ebbing and flowing well in which the water rises until a stone trough is filled. The trough may then begin to empty at once, or there may be an interval of 15 or 20 seconds before it does so. The process will take between two and three minutes, at the end of which time there will be an interval of from five to nine minutes before the cycle commences again.

The water is quite cold and has no apparent connection with any sort of geyser action. It is presumed that a series of syphon-shaped connections through the rock join chambers of different sizes. All explanations are purely hypothetical, and the cause of the interrupted flow of the well is still a mystery.

RIVERS

Few common features of the landscape are more garbled in nomenclature than are rivers. Rivers are said to *rise*, whereas water runs downhill all the way. A river is said to have its *head* at its source, and its *mouth* at the place of its discharge. According to its nomenclature a river might be a biological monstrosity. This confusion in terminology truly represents a confusion in popular understanding. The origin and nature of rivers, and their relation to the surrounding country has only recently emerged from the unorganized natural philosophy of past generations.

Wherever water drains from the surface of the land, there is the source of a stream. At that place the stream may be small, but as it flows along it gathers the drainage of other trickles or streamlets, until it joins a master stream.

The master stream itself is the composite of many tributaries, and, as time goes on, the stream enlarges its drainage system, lengthens its tributaries and extends its drainage basin. Ultimately the borders of its drainage basin reach to those of a neighboring master stream, and the line of division between each system is a watershed. The basin of drainage is also called a "catchment area," to indicate that the river depends upon that area for the supply of its water. Most of the water

during rainfall comes directly as the run-off from impermeable or already saturated rocks; this is the "immediate run-off." Much water joins the streams—long after rain has ceased—by means of springs and seepages, which is the "delayed run-off." Streams which depend upon immediate run-off are temporary streams, but all permanent streams depend upon the escape of ground water from their valley walls for a constant supply of water. Many stream systems include within their drainage basin, lakes, swamps, snow-fields, and glaciers, each of which may truly be said to be a source of the main river. Nothing seems less logical than to pounce upon one individual lake, spring, or glacier, and to designate that particular contribution of water as *the* source of a river. Nevertheless, nearly every large or famous river is supposed to have a particular source.

RIVER EROSION

In general large mountain ranges form the divides between drainage systems. Indeed, many mountains owe their elevation above the surrounding country to the removal of land by river erosion. In the natural course of events, if rivers run long enough, not only do they wear their basins to a featureless plain, but they remove the mountain ranges themselves. In many parts of the world today, only low hills remain to mark the location of former skyscraping mountains. Even though reduced to low rounded hills, the geographical location of the divide between great drainage systems may not have changed very much during the tremendously long period of river planation. This concept of the ability of running water to wear down unaided a continent to a featureless

plain is an American invention. Advanced late in the last century it has now won nearly universal acceptance, and has done much to make reasonable our interpretation of rivers in relation to landscape.

Energy is the ability to do work. Work, mechanically speaking, is the transfer of force through distance in accomplishing a desirable purpose. Rivers have the ability to do work by virtue of their supply of natural energy. The energy of a river is measured in terms of its quantity of discharge and the speed at which it goes. Thus a little stream must be going very fast indeed to provide considerable energy, but a large stream need not go so fast to develop equal energy. For great energy we seek large streams of great speed.

In engineering projects men build dams in order to increase locally the gradient of the stream, thus achieving a huge increase in velocity without loss of volume. In nature we see that water falling over cliffs has the greatest possible velocity, going down cataracts or rapids it goes very fast, but flowing over plains it cannot go fast. The slope or the gradient controls the speed of a river; the organization or development of its drainage basin contributes to its volume. Every stream therefore, whether harnessed by man or not, has a fund of energy which might be applied to useful work, but which, in a state of nature, is largely dissipated.

APPLICATIONS OF ENERGY

Rivers use a lot of their own energy in overcoming the internal friction of water, merely in flowing. In addition to that, they use energy in overcoming the friction against the boulders and obstructions in their bed, in going

around bends, in crossing from one side of the valley to the other, and in overcoming the drag of the meanders in the course. More energy is consumed in actually wearing away the bedrock, in rolling and carrying along boulders, sand, and mud. The actual work of transporting downstream the

FAILURES OF ENERGY

This results in the deposition of silt and sand whenever a stream overflows, in the clogging of channels with silt and sand bars, and finally in the building up of new land surfaces at the place of discharge, making levees along the rivers and deltas at their

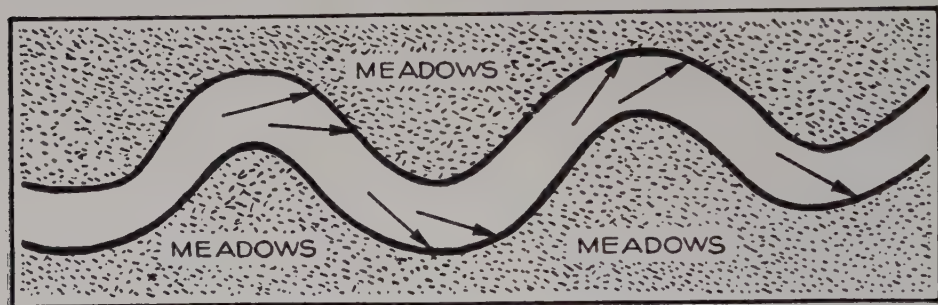


Fig. 4. How a river undermines its banks by continually flowing against them at the bends

material swept into the main stream by its tributaries and by rainwash is very great. The supply of energy, of course, is constantly being renewed from place to place along a river's course, so long as there is enough gradient to cause gravity to make the water flow. However, it is nearly always true that the gradient of a stream decreases as it approaches its place of discharge. Its energy per mile may be expected to decrease accordingly. However, this loss is offset considerably by the increase in size of the streams as they gain additions from their tributaries. The result is that the upper parts of a stream system have energy to spare, and they erode the land vigorously. The lower stretches of the same stream, however, are relatively deficient in energy; not only does the stream fail to erode the land surface any further, but it actually deposits part of its load as it nears the discharge.

The actual gradient, or fall per mile, varies greatly with different rivers as well as along the course of every individual stream. The Danube falls about 10 feet in the mile, in its higher reaches, but at Vienna the fall is only about one foot in two and one-half miles. The Nile has a fall of only about four inches to the mile below Cairo; and the Thames, 21 inches to the mile. The Amazon falls only one-fifth of an inch in a mile over the final 700 miles to the mouth. The Missouri River falls about 300 feet for the 300 miles above Bismarck, North Dakota, and the Mississippi falls about 400 feet in the 1,270 miles between St. Louis and the Gulf of Mexico.

In general the rivers with the greatest drainage basins are the longest rivers. The longest river in the world is the Mississippi, which, with the Missouri—the two are usually regarded as one—extends for 4,200

miles; the Amazon is 4,095 miles long. The longest rivers in Asia are China's Yangtze Kiang and Siberia's Yenisei, both 3,200 miles in length. Africa's representatives are the Nile, 3,500 miles; followed by the Congo, 3,000 miles. The best Europe can do is the Volga, 2,300 miles; followed by the Danube, 1,750 miles. The Thames, one of the most important rivers of the world, is a mere 210 miles in length, but it is important only for its estuary, so that its small size is no drawback. Similarly, the Hudson River, as such, has a very moderate discharge, but its estuary makes possible the port of New York.

TYPES OF RIVERS

The character of a river is determined by the relative progress it has made in its job of wearing down the land surface, by the climate of

its drainage basin, and by the nature of the rocks which underlie the region. Ordinarily rivers might be expected to run straight down any slope which they may find. In general they do. However, in the course of time all streams develop a meandering course. Old streams, that is, streams well along in the course of their development as drainage systems and as agents of erosion, generally have tortuous courses, twisting and turning in an extraordinary manner. The River Jordan, for example, winds so much over a distance of 70 miles between Lake Tiberias and the Dead Sea that the length of its course between those two places is over 200 miles. After a period of time any river will undermine the banks along which it flows (Fig. 4), so that ultimately the weight of the ground above is too much for the bank to support and it



U.S. Geological Survey

Fig. 5. An aerial view of the meanders of the San Juan River in Utah

falls into the river. Thus at each bend of the river the outer banks are being cut away, and, in the course of time, the valley is cut deeper and deeper.

Sometimes such a meandering stream may become involved in a more or less widespread uplift of the land. In such a case the old shape of the stream remains but its behavior changes. A meandering stream is one which usually is depositing more than it erodes, but uplift increases the gradient of the stream and causes it to erode actively. Thus the bottom of the stream is cut down deeper and deeper, until it is a sunken channel, entrenched far below the level of the uplifted region. Such a river is the Colorado. For 300 miles it flows through the Grand Canyon—one of the marvels of the world. The uplifted surface is 8,000 feet above sea level. The Colorado River has cut down to 3,000 feet above sea level and is still actively down-cutting. The Canyon is a mile deep and about 12 miles across from rim to rim. Unless we can conceive of an uplift of the land where a well-established river had made itself a valley and where speed of uplift was moderate enough so that the running water could cut down almost as fast as the land was uplifted, we have no explanation of such a freak of nature. Other rivers of this type are the San Juan River, in Utah, which has carved wonderful, entrenched meanders; the Columbia River, flowing transverse to the Cascade Mountains; and the Susquehanna, which cuts through the main ridges of the Appalachian Mountains in Pennsylvania (Fig. 5).

We know water cannot run uphill, but we note that many rivers seem to draw tributaries from the other

side of a great mountain range, making "water gaps" through or across the main ramparts of the mountain mass. Harper's Ferry, on the Potomac River, is such a place in the Blue Ridge Mountains. Similarly, the Indus and the Brahmaputra rise north of the front wall of the Himalaya Mountains, flow southward through great passes and deploy in the plains of India. All such rivers were rivers in mature development before the mountain ranges were uplifted and carved by running water. They constitute a particular and definite type known as "antecedent" streams. When understood for what they really indicate as to the history of the surface of the earth they are in themselves truly among the marvels of nature.

PECULIARITIES OF CERTAIN RIVERS

The land over which a river flows may impart some particular characteristic to it. The waters of the Salt River in Australia and the Rio Salado in the Argentine are saline, because they have taken up certain mineral salts from the soil over which they flow. In the United States we have numerous salt rivers, salt lakes, salt licks, indicating exactly the same sort of thing. In places there are even hills of salt in climates dry enough to save the salt from being washed away. In Death Valley we have great deposits of soluble borax concentrated in a basin of interior drainage. The salts have been dissolved from the surrounding rocks and carried into Death Valley where the streams have promptly dried up, leaving the borax and other salts as natural concentrations of economic importance. The waters of the Rio de Vinagre, of New Granada, in Central America, have a vinegar-like taste, because of the great

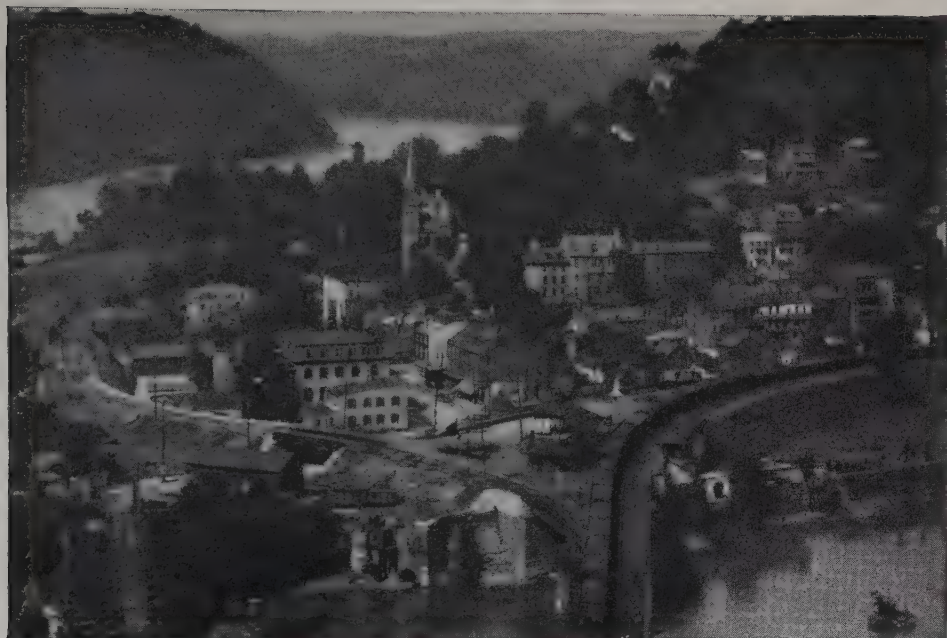
*Keystone*

Fig. 6. Harpers Ferry, West Virginia, is a "water-gap town," situated on the confluence of the Shenandoah and Potomac Rivers, which cut through a gorge in the Blue Ridge Mountains

quantities of sulphuric acid which they contain.

Some rivers are colored, as in Algeria, where one tributary of a river is impregnated with iron and another with gallic acid taken up from peat marshes. As these two ingredients are used in ink-making, it is only natural that when the two tributaries unite the result is a river literally "as black as ink." Of the others, there are "white" rivers like the White Nile; the Red Rivers of the United States; the Hwang Ho, or Yellow River of China; the "Yellow Tiber," and, finally, the Blue Danube. Most of these "colored rivers" owe their reputation for color to matter held in suspension by the waters, coupled perhaps with a little imagination on the part of those who so named them!

The Rio Tinto, in southern Spain, is perhaps the greatest wonder of them all. High in the hills near the old mines of Tarshish—which were worked in the days of King Solomon—the stream is green as emerald. Outcrops of iron pyrite provide ferrous sulphate which is brilliantly green. Water is scarce and the pyrite is abundant. Consequently the small streams that flow are brightly colored. As the water trickles through the mountain valleys, all blue with wild lavender, the color of the water gradually seems to change to purple-brown. Wherever the green stream runs through sandy stretches, wherever water collects behind the sand bars, the pools of water seem to turn red. As the stream draws nearer to the sea, the water changes color com-

pletely to blood red. This is simply explained by the oxidation of ferrous salts, which are green, into ferric oxide, which is as red as the common iron oxide known as rouge. No wonder that the people have long named the Rio Tinto—Red River!

WATERFALLS

Just as water gaps are a sign of antecedent streams, so waterfalls and cataracts indicate that a stream is still in the heyday of its early youth. Waterfalls result from the failure of the running water to have worn away that part of its bed, and as such, waterfalls are temporary incidents in the development of a stream. Waterfalls are generally due to changes in the geological structure of the river bed, as, for example, a change from a hard to a soft rock, whereupon the soft rock is worn away by the falling water, thus giving the fall an increasing depth as time goes on.

Waterfalls are most common where stream gradients are steepest, that is, near the headwaters of a drainage system in mountains. Without considerable local geographical relief there can be no possibility of a high waterfall. Mountains are formed by the intrusion of strong, massive, igneous rocks like granite into a zone of sharply folded bedded rocks. The folding causes the layers to stand on edge and, consequently, from bed to bed the river erosion varies according to the varying character of these layers. Strong layers wear slowly, weak beds wear fast. This results in a series of steep or precipitous places in a river's course alternating with rapids or with places of low gradient. In general the attitude of the folded beds causes the exposed edges to run parallel to the main length of the

mountain range. Consequently, rivers flowing from the mountain divides usually pass transversely across the edges of these rocks of alternating or varying strength. Wherever there are antecedent streams cutting through mountain ranges, we may expect to find waterfalls.

We find them particularly on the rivers that cut through the Rockies and the Andes, and on those African rivers that flow from the interior to the ocean and have to cut through mountain ranges that lie in their paths. On the other hand, waterfalls are seldom found when rivers run parallel to mountain ranges, or in rivers that flow over prairies or plains. No waterfalls are found, for example, on the lower Amur or on the lower Yangtze Kiang, which is navigable for 1,700 miles, but in southern China where the Si-kiang and the Songka have to cross the mountain ranges, waterfalls are numerous.

Some waterfalls are more picturesque than others. This depends largely on the geological formation of the locality in which they are situated. Some are long thin "pipes" of water which by the time they reach the end of their journey are little more than columns of attenuated spray, so great is the height from which they fall. On the other hand, there are stupendous falls where millions of gallons of water pour over vertical precipices every minute. Other falls descend step by step, over a considerable distance, forming a cataract rather than a waterfall.

Waterfalls are generally very destructive to the river bed and play an important part in the denudation of the land. This is particularly the case if the bed of the river is a hard rock lying in the softer shales or sand-

stones. Rushing over the ledge, the water dashes with considerable force against the softer rocks beneath, wearing them away and undermining the hard stratum above. Unable to support its weight, the rocky ledge breaks away and falls into the river below (Fig. 7).

and 3,150 feet in width and 155 feet in height, respectively. About 94 per cent of the total water of the river passes over the Canadian Falls, where it has excavated a basin as deep as the height of the Falls.

Although the river has cut a deep chasm in the shale, it has not been

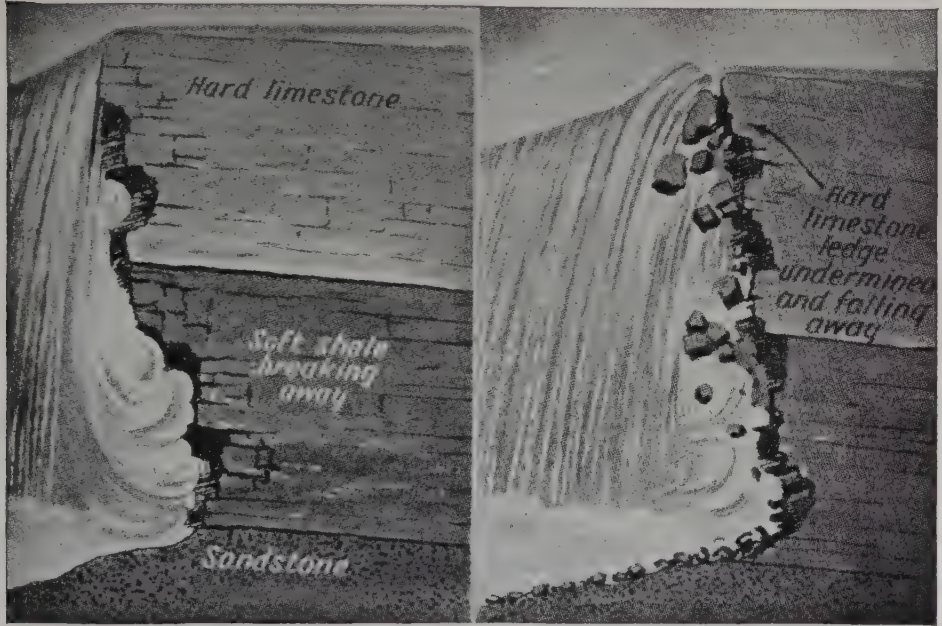


Fig. 7. How waterfalls recede. The water cuts away the soft underlying rock so that the harder strata on top are undermined and, being unable alone to support their own weight, finally break away and fall into the river below

MIGHTY NIAGARA

Such is the case with the Niagara Falls, perhaps the most famous, but by no means the largest, waterfall in the world. These falls are caused by the overflow from Lake Erie, which forms the Niagara River. This overflow plunges over a ledge of hard limestone, resting on a bed of soft shale. The river at this point is divided into two by Goat Island, forming the American and Canadian Falls—1,060 feet in width and 162 feet in height,

able to make an equal impression on the hard limestone, although the water at the bottom of the fall is undermining the softer strata below in the manner already described. This has resulted in the Falls moving slowly backwards for thousands of years. This recession is believed to have brought the Falls to their present position, instead of the original position some seven miles nearer the shore of Lake Ontario, where Queens-town now stands (Fig. 8). It is esti-

mated that since the Falls were discovered in 1678 by the Jesuit missionary, Father Hennepin, they have receded about 1,000 feet nearer to Lake Erie.

Four of the largest waterfalls in the world are situated in South America. Only a few white men have ever seen them.

WORLD'S LARGEST WATERFALLS

The Kaieteur Falls, on the Potaro River, in the wilds of British Guiana, were discovered in 1870. The river flows over a sandstone and conglomerate tableland into the valley 822

feet below, so that the Falls (Fig. 9), are about five times the height of Niagara.

The Paulo Affonso Falls, in Bahia, Brazil, divide into four and plunge into a gulf some 300 feet below. Five miles above the Falls the river is a mile and a quarter in width, but it suddenly contracts to a width of 56 feet so that an enormous volume of water is hurled into the abyss with tremendous force.

The Iguassu Falls, partly in Argentine and partly in Brazil, are situated in the heart of virgin forest beyond Asuncion. Here the Curityba river

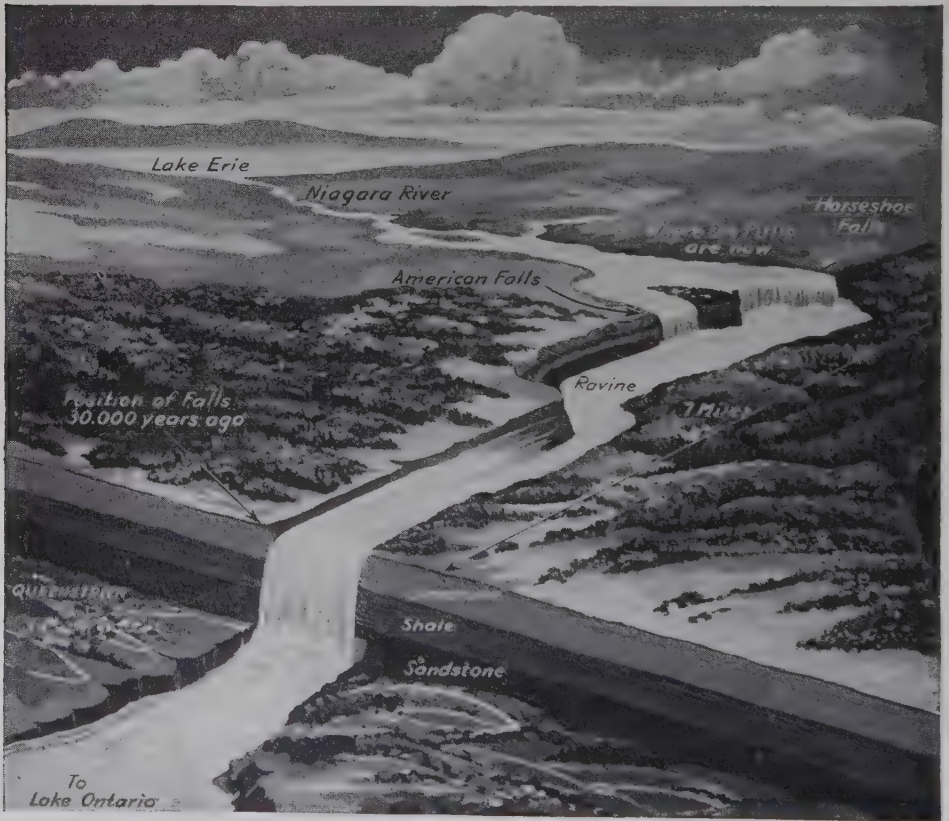


Fig. 8. Where Niagara Falls were 30,000 years ago. Since that distant time the Falls have receded seven miles up the gorge. In some future age the Falls will reach Lake Erie

descends from the great Brazilian plateau to the lower levels, the Falls being about 1,500 feet wider than Niagara and about 210 feet in height.

Fourth of these great waterfalls of the world are the Guayra Falls on the Paraná River, which lower down becomes La Plata. Their height is 373 feet and there are 18 separate falls, the river descending by enormous steps that form a unique series of cascades and gorges, in which 20-foot waves are formed and great clouds of spray that can be seen for miles around. The flow of water is over 500,000 cubic feet per second—more than double that of Niagara. If the Falls could be harnessed they would provide the greatest source of power in the world.

In Africa, the Victoria Falls are 343 feet high, collecting the waters of the Zambesi River, which is two miles wide above the Falls, into a narrow fall and gorge less than 400 feet wide. The Tugela River forms a much higher waterfall in Natal, South Africa, leaping 1,800 feet in one drop, and in two more steps jumping down another 1,000 feet, to make a total fall of 2,800 feet. A wonderful and rather inaccessible fall is the Grand Falls of the Hamilton River, in Labrador. The Hamilton River rushes down a series of little falls and cataracts, dropping 200 feet in five miles, and then, with a thunderous roar heard 20 miles away, plunges over a drop of 302 feet. The greatest fall in the world is probably that discovered in May, 1938, by Dr. Paul A. Zohl. Dr. Zohl has been no nearer than he could scout in an airplane. Flying about 80 miles northeast of Mt. Roraima, in British Guiana, he saw a branch of the Karanang River dropping over a precipice onto a ledge about 1,400

feet below. There the stream divided into two forks which continue as falls into the bottom of the chasm, making a total drop of not less than 3,000 feet.

DELTA AND THEIR FORMATION

At the mouth of some rivers the material brought down by the waters forms deltas. They are so called because the shape assumed by this deposited material is roughly that of an equilateral triangle, thus resembling the Greek letter *delta*, the capital sign for which is Δ . Deltas form as the speed of the river slackens, and this slackening is due to the fall of the bed decreasing as it approaches the sea. The tendency, then, is for much of the matter in suspension to be deposited—first the gravel and the sand, then the finer materials, leaving only the finest particles; and even they eventually are deposited. If the sea into which the river discharges is not disturbed by currents, and if there is little tidal scour, the sediment accumulates into a fan-shaped deposit. Obviously this can only occur if the materials are deposited at a greater rate than that at which they are carried away by the movements they encounter in the sea. In time this sediment may silt up the mouth of the river so that a new channel, or channels, must be formed. These again form secondary deltas, the deposits constantly accumulating and forming new alluvial land at the mouth.

The nature of this delta land varies according to local conditions and the nature of the material brought down. The land may be swampy, as in the case of the great Indian rivers, the Ganges and the Brahmaputra, in the marshes of which grow mangroves and nipa palms.



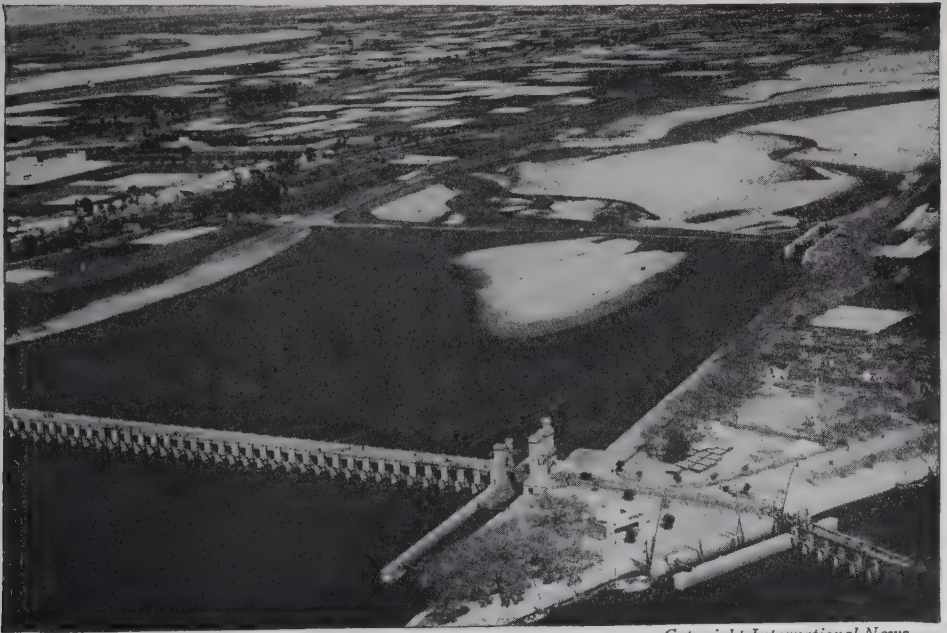
Fig. 9. The wonderful Kaieteur Falls on Potaro River in British Guiana. The falls are four times the height of Niagara and have a drop of 822 feet

However, swamps and tidal marshes can be drained. In the Netherlands they built dikes around such areas, pumped out the water, and made cultivated fields in the areas thus reclaimed from the sea. Unless the lowlands had been originally made up of soil deposits rather than sea sands, the reclamation of these "polders," would have been impracticable. Once drained, the delta subsoil can be made productive. Nearly three-fifths of the Netherlands are made up of lands reclaimed from inundations. Unless the delta lands were saturated with fresh ground water, which flows from the Rhine and other river channels towards the sea, the drained areas would be gradually flooded by the seepage of sea water. Soil soaked with sea water of course would not be productive. It

follows that polderlands cannot be made anywhere, but only in deltas or piedmont areas underlain with ground water draining towards the sea.

BRINGING DOWN NEW LAND

Deltas are often valuable additions to existing land, and in the course of time they may cause great changes, as in the case of the River Po. In times gone by the town of Adria was a port on the Adriatic, but owing to the accumulation of deposits at the mouth of the river, it is now 20 miles inland. Sea shells have been found in the Valley of the Euphrates, near Babylon, although the site of Babylon is now some 400 miles distant from the river's mouth. The Plain of Babylon has been extended by silting up from this point, and the rivers of this valley now discharge their waters into



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Fig. 10. Aerial view of the Nile Delta. Note the water in the left upperhand corner. This interspersing of land and water is characteristic of delta formations



Fig. 11. United States Army Engineers lease a private industrial dredge boat for channel enlargement of the Mississippi. This work is known as "corrective dredging"

the Persian Gulf some 350 miles further seaward than in 10,000 B.C.

There is an enormous delta in Lower Egypt produced by the Nile, which branches into two main streams some 120 miles above the mouth. The Nile Delta is enclosed in a triangular area with Cairo, Rosetta, and Damietta at its corners, and it is clear that the area extending from Cairo to the sea, a distance of over 100 miles, has been brought down by the Nile, which at one time entered the Mediterranean at Cairo. From borings that have been made it is evident that the alluvial deposits extend to a depth of 120 feet or more. In the time of Herodotus, Memphis was on the shore of the sea, but today it is 100 miles inland. The land between is composed of the disintegrated rocks and soil washed down by flood waters from the great drainage area of the Nile Valley.

In Britain we find an illustration of the changes that may be brought about in a similar manner, though on a much smaller scale. In Roman times there was a channel wide enough to admit the Roman fleet between the Isle of Thanet and the coast of Kent, but this channel no longer exists, the so-called Island being now actually part of the mainland, due to deposits of alluvium. In the United States the Colorado River carries enormous quantities of solid matter to the sea—in a year it carries sufficient material to cover 105,000 acres to the depth of a foot—and an enormous delta has formed in the Gulf of California. Year by year this delta is increasing in size.

With the building of Boulder dam and the damming of part of the Colorado River waters, much sediment will accumulate above the dam, the volume of the flood waters will be de-

creased, and the amount of sediment carried to the delta will be reduced.

The delta of the Mississippi covers an area of 12,300 square miles, the river depositing some 6,000,000 cubic feet of material every year. A well sunk in the Mississippi delta went down to a depth of 620 feet without reaching the limit of the alluvial deposits. The delta of the Mississippi forms a huge tract of swampy land, through which wander aimless waterways, for the most part shallow and impassable to any but small boats.

The main channels of the Mississippi River are kept open and useful for navigation by the system of jetties which were first successfully installed

by Colonel Eads, an American engineer. Traffic is routed through only one channel, which is kept deep enough for safe navigation, whereas numerous other channels, called "passes," serve to allow the flood waters of the river to escape to sea, regardless of whether or not they are silting up their channels.

WORLD'S LARGEST DELTA

The largest delta in the world is the Sunderbunds, formed by the Brahmaputra and the Ganges, both of which rivers flow down from the Himalayas. They form a delta that has an area about half that of the state of Illinois, and is increased each



Fig. 12. The beginning of this long suction head drag was visible in the lower left-hand corner of Fig. 11. Here we get some idea of the length of this equipment. At the end nearest the boat is a sharp cutting instrument which digs into the silt and river deposits

year by large quantities of mud. Up one of the branches of this delta, at the mouth of the Hooghly River, on which Calcutta stands, a great river bore sweeps at certain times of the year. It is first seen at Buffalo Point, advancing at the rate of 20 miles an hour, and by the time it has reached Buj, 30 miles further up, it has a crest four feet in height. At Chundurah, 17 miles above Calcutta and nearly 70 miles from its starting point, the bore reaches a maximum height of six or seven feet. These river bores are caused by tidal water meeting the swiftly-flowing waters of a river in a comparatively narrow channel so that the incoming water is "piled up," as it were, into a great wave that sweeps up the river.

Most rivers carry too little sediment or are not large enough, to form deltas. The outlets of many rivers are kept open by the tides, the ebb tide coupled with the flow of the river taking the sediment away. In some cases, however, the sediment is piled up into a "bar"; and when the piling up occurs further out to sea, the deposit forms "shoals" or "banks." The port of Liverpool, at the mouth of the Mersey River, in England, is handicapped by a bar outside the harbor. It is necessary continually to have dredgers at work to keep a clear passage at the mouth of the river, the danger point being marked by the Bar Lightship. London, the greatest port in the world, at the mouth of the Thames, is an example of a harbor in a tidal river estuary. Shoals form in the estuary, but there is always sufficient scouring action by the tides to keep the channel open to navigation, despite the 14,000,000 cubic feet of solid matter that is carried down to the sea every year.

A large bar obstructs the harbor of Portland, at the mouth of the Columbia River. Careful engineering is required to make the tidal currents scour away the river deposits as fast as they are brought to the sea. Many of the smaller harbors on the coasts of New Jersey and Virginia must depend upon the tidal scour to keep their outlets open for navigation.

FORMATION OF ICE

Ice, the solid form of water, consists of large numbers of minute but definite forms known as crystals. Although much has been learned about crystals, particularly by means of X-rays, the actual process of crystallization remains one of the mysteries that science has yet to solve. It is apparently a peculiar molecular arrangement in which each crystal displays a definite geometrical form, bounded by plane faces. These forms are assumed by pure substances when they change from the state of liquid or gas to that of a solid. Each substance, in conformity with its molecular structure, has a corresponding form, and other crystalline properties, peculiar to itself. The constancy of the angles between neighboring faces of a crystal is so definite, that a measurement of appropriate angles on a crystal form serves in many cases to identify the substance both crystallographically and chemically.

Water expands when heated and contracts when cooled at and above a temperature of 39.2° F. Below that temperature an opposite action takes place and it expands until it reaches 32° F., when ice is formed. The expansion of water when freezing is, of course, the cause of burst waterpipes, but owing to the water in them being solidified the actual burst is not gen-

erally detected until a thaw sets in and the ice in the pipes is converted back to the water that escapes through the "burst."

Water under high pressure freezes at a temperature lower than normal. Should the pressure be suddenly removed from water below normal freezing temperature, the water immediately freezes and expands with tremendous force. As a result of this expansion the resulting ice is of less density than water. A solid block of ice weighs less than an equal bulk of water. If we have a volume of water weighing, say, 1,000 pounds, ice of equal volume will weigh only 917 pounds. This is the reason that ice floats in water with about 90 percent of its volume below the surface.

EFFECT OF SEVERE FROST

When a frost is severe, ice forms very quickly—on occasions, indeed, water will freeze as it leaves the nozzle of a fire hose and on a building that is burning (Fig. 13). On occasions of severe frost rivers are completely frozen over—the St. Lawrence, for instance, is closed to shipping for several months each year. It is not often that the large rivers in Western Europe are frozen, but occasionally this does happen. A few centuries ago

whenever the Thames was so frozen, "Frost Fairs" were held, and swings, coconut shies, and other fairground delights, were erected on the ice. At night huge fires provided light for skating, skittles, and other forms of amusement.

In the winter of 1683 there was a celebrated Frost Fair, when the frost lasted for two months and the river was frozen to such a degree that another city seemed to have been created on it. Streets of booths were erected and occupied as shops by all kinds of tradespeople, and even a printing press was set up on the ice. Coaches plied on the ice from Westminster to the Temple, and bullbait-



Fig. 13. The cold during a fire was so severe that the water froze as it fell on the burning building

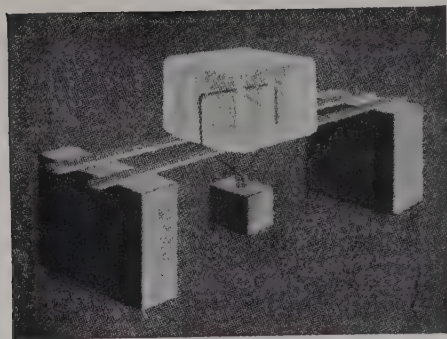


Fig. 14. Demonstrating regelation. In time the wire will be pulled right through the block of ice but it will not divide it

ing and horse racing were the order of the day—and night, too! The last Frost Fair was held in 1814; since then something seems to have happened to the weather, for the frosts have not been sufficiently severe to enable the Fair to be held in London. Such winter carnivals, of course, have been common in other parts of Europe. Here in the United States, an ice carnival is held every year in St. Paul, Minnesota, where a marvelous ice palace is erected, and winter games and sports are enjoyed by all. In medieval days winter was a time of gloom, privation, terrible hardship, and often famine. All over North America, and Europe in times of peace, skiing, mountaineering, snowshoeing, skating, and winter camping have made winter into a season of happiness and health.

Ice has many curious properties, not the least of which is its plasticity under pressure but not under tension, for it cannot be drawn out into filaments. In the form of a glacier it moves down the valleys, and although traveling comparatively slowly it moves at a uniform rate under the pressure of its own mass in spite of tremendous resistance to its movement.

It also has the peculiar property called “regelation,” which means re-freezing. Two pieces of ice pressed together will freeze into a single piece. This property may be demonstrated by placing a block of ice on two supports and suspending a heavy weight on a wire that passes over the block of ice. The weight pulls on the wire so that it gradually cuts its way through the ice, the two pieces produced becoming united again above the wire. Thus, after a time, when the wire has cut half way through the block, it appears as though the wire had originally been frozen in the ice (Fig. 14).

DOES SALT WATER FREEZE

Some people think that salt water does not freeze. We need not even ask such people to take a trip to the Arctic or Antarctic circles to dispose of this idea, for they can set out salty water during cold weather and watch it freeze. Salt water freezes at a temperature of from 26.7° to 31° F., according to the degree of saltiness of the water. In the Polar Seas ice spicules or needles form in water that is freezing. These notched blades of transparent ice increase rapidly in number until they form a layer over the whole surface, this layer being known as “bay ice” because it forms more easily in sheltered bays. This bay ice at first does not form a solid sheet, but is very limber, making the familiar “rubber” ice, which is still quite strong enough to check a boat moving through it. As the freezing continues the effect becomes increased, and waves that previously could distinctly be seen in the ice become less pronounced until in due time the sea is completely frozen over with this first thin covering. At first

it is black, or invisible, and more or less plastic, but later it changes to white and becomes a brittle mass that completely covers the sea, when it is known as "field ice."

In open polar seas the ice forms separate small sheets, which grind against one another, shattering their edges into rims, making them "pan" ice. Finally the "pans" coalesce into continuous floes of ice.

In its first year, polar ice cannot exceed seven feet in thickness, unless it is piled up by the wind and waves. In the second year only about three feet can be added, the growth being more rapid when first formed and becoming slower as the thickness increases. Despite statements that the thickness of polar ice is sometimes 18 feet or more, the general experience seems to be that its average thickness is about eight feet except in the case of ice masses that are due to piling up, when the ice may be of any thickness up to 1,500 feet.

Of all the wonderful phenomena displayed by nature there can be none more marvelous or mysterious than the tiny snowflake. Yet this feather-like accumulation of crystals can do tremendous damage and cause great loss of life and property—it can even cause disaster to an army, as Napoleon learned to his sorrow at Moscow. Nearly every winter, snow causes dislocation of road transport and can involve the Street Departments of our great cities in considerable expense.

MODERN SNOW CLEARANCE

Today speed is the secret of modern snow removal, the problem being altogether different from that of the days when heavy vehicles capable of turning snow into slush were few and far between. If not cleared away from

the streets of our cities and towns, the snow may constitute a serious nuisance and result in great industrial losses.

We have already seen that the atmosphere contains a large amount of water vapor. When this vapor freezes it forms clear transparent crystals, each individual crystal so small as to be invisible. These crystals form a nucleus that falls through the air, is caught by rising currents, and falls again, the process being repeated again and again. Meeting ever-changing currents of air and varying conditions of moisture-laden atmosphere, the crystals develop, gathering together in "families" of perhaps a hundred or more, and slowly sinking to earth as their weight increases.

Snowflakes are of various sizes and may measure from over an inch in diameter down to almost invisible little specks. Their size depends on the atmospheric conditions under which they are formed. The largest ones are formed at temperatures of nearly 32° F. and the smaller ones at a lower temperature and generally in the higher atmosphere at heights of perhaps eight or ten miles or more. The crystals are arranged about a center at an angle of either 60° or 120° and they are invariably either six-pointed stars or extremely thin plates of hexagonal shape. From the nucleus of the six-pointed stars, or pyramids, secondary rays branch off at the same angle as the parent rays, each part of the general pattern being repeated six times around the nucleus. The arrangement of particles about the ends of these axes indicates a form of symmetry which ice shares with other common natural crystals, such as quartz or rock crystal, and calcite or Iceland spar. This truly marvelous

property of repetition of form, such that each feature is repeated upon rotation of the crystal six times, is known as symmetry. Symmetry is one of the essential properties of crystals, according to which fundamentally they are classified and identified, either by the measurement of their angles, or by the analysis of their X-ray patterns.

Prolonged study has been made of snowflakes over many years and no two exactly alike have yet been seen. They exhibit the most beautiful forms and such unique patterns that they have often been used as a basis for designs by decorators, jewelers, and other craftsmen (Fig. 15) who capture in more lasting media these marvels of nature.

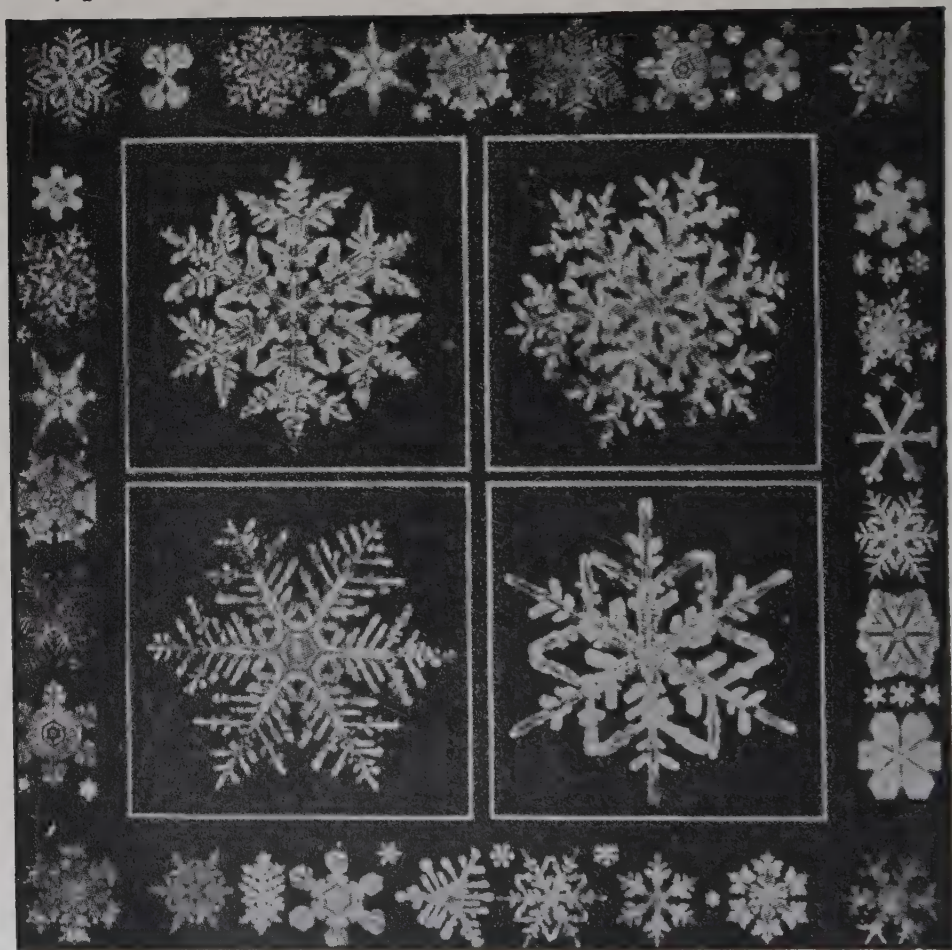


Fig. 15. Some of the innumerable forms taken by snowflakes, arranged in a pattern. Some of the flakes here are duplicates, but these are merely arranged thus to form a design, for out of the countless thousands examined, no two snowflakes have ever been found to be alike. They are always six-pointed stars or thin plates of hexagonal shape with the crystals arranged about the center at 60° or 120° angles

STRUCTURE OF SNOW

Actually, snow is colorless, being but frozen water. Its apparent brilliant whiteness is due to the reflection and refraction of light from the numerous surfaces of the large number of crystals. Its opaqueness is due to the presence of air in the snowflakes, without which they would be as transparent as ice. We have already mentioned colored rain, and similarly we find several records of colored snow. Darwin tells us that during his passage through the Cordilleras, in 1835, the footsteps of the mules were stained red as if their hoofs had been covered with blood. At first Darwin supposed that the color was due to dust blown from the surrounding mountains of red porphyry, but later found that there was another explanation. As with red rain, red snow may be due to the presence of countless minute plants or *algae*. In this case they are known as *Protococci nivales*. These microscopic spheres or colorless cases measure less than .001 in diameter. They are so prolific that an Arctic or Alpine landscape has been changed from white to red overnight. Nansen saw drifts of rose-colored snow, caused by similar minute red *algae*, *Spaerellae nivales*. He also mentions yellowish-green patches of snow, due to the presence of another species of *algae*.

Snow cannot fall at places where the general temperature of the atmosphere is never at freezing point, for it would be melted before it reached the ground. For this reason snow has never fallen at Buenos Aires, or at most places less than 30° N. of the equator and within a somewhat wider limit to the south of the equator. The lowest latitude at sea level

in the northern hemisphere at which snow has been seen is Canton, China (lat. 23°) but in the southern hemisphere it has not been known to fall at sea level farther north than at Sydney, Australia (lat. 34°).

SNOW ON THE EQUATOR

There are, however, snow-covered mountains almost *on* the equator, as, for example, Mount Kenya, in Africa, or Mount Kilimanjaro, also in Africa, which rises to a height of 19,400 feet, only 3° from the equator, and has a perpetual snowcap. The equatorial volcano, Chimborazo, in South America, also has snow. The elevation at which mountains are covered with perpetual snow is called the snow line (Fig. 16). The upper snow line is the altitude above which the temperature never is high enough to permit all the snow to melt, and the lower snow line is that at which the temperature is high enough to allow most of the snow to melt in summer, but where snow may be found the year round.

The position of the snow line depends on variable causes such as the state of the summits, the comparative altitude and physical features of the surrounding country—for instance the particular exposure to which the mountain is subjected—and so on. It is also modified by the amount of snow that falls, for should large quantities fall in winter it requires a greater length of time to melt away completely than is the case if only a small quantity falls. In the Himalayas, for example, the snow line varies from 16,600 feet to 19,000 feet and is 2,000 feet higher on the northern side of the range than on the southern, despite the fact that the latter is nearer the equator. This is accounted for by the winds blowing on the south side

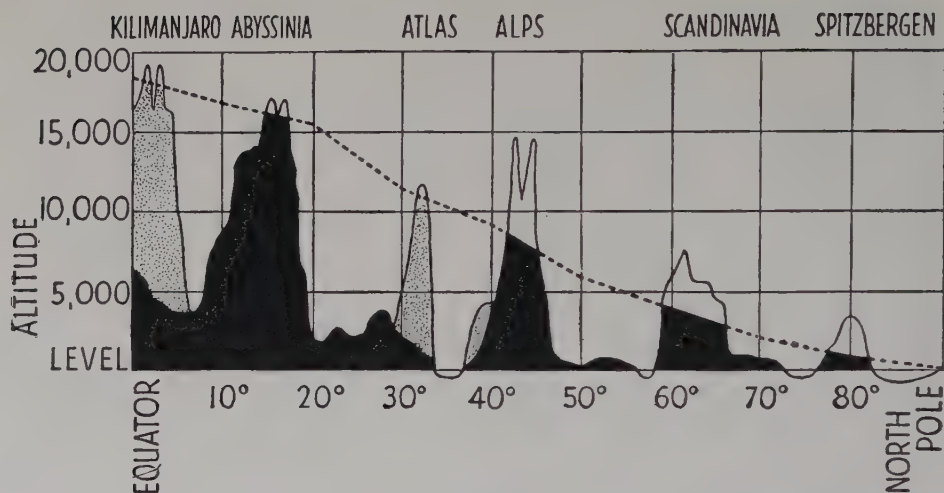


Fig. 16. The snowline in the Northern Hemisphere, showing the gradual decrease in its altitude from the equatorial regions to the North Pole

from the Indian Ocean, for these winds are heavily charged with moisture. This is deposited on the southern side as snow, the falls being heavier here than on the northern slopes. On the other hand, the northern side is subjected to dry winds that blow across the plateaus of Tibet, evaporating the snow on the northern slopes, and raising the height of the snow line on that side.

As a general rule, the altitude of the snow line naturally decreases from the equator to the poles. At the equator the snow line is at a height of about three miles (16,600 feet) above sea level; in lat. 12° N., on the mountains of Abyssinia, it is 14,000 feet; at the Atlas Mountains, south of the Mediterranean, 11,500 feet; in the Alps, 9,000 feet; in Scandinavia, 6,800 feet; and at Spitzbergen, only 1,500 feet. In the polar regions there is, of course, perpetual ice and snow at sea level.

A similar gradation from a very high snow line at Chimborazo, south-

ward almost to sea level at Tierra del Fuego, and northward to sea level in Alaska and Greenland, may be traced in the western hemisphere.

THE "ABOMINABLE SNOWMAN"

In the perpetual snows of the Himalayas have been seen footprints that furnish one of the great mysteries of science. The natives believe that they are caused by a creature that is half man and half beast, known as the Abominable Snowman. This creature has not so far been seen by any European. Yet there is a strong belief in these Mi-go or Murka—as they are called by the superstitious natives of Nepal and Tibet—and sufficient indirect evidence has been gathered by European travelers and mountaineers to warrant an expedition to investigate the mystery.

The legend of the Abominable Snowman extends for hundreds of miles through Nepal, Tibet, Sikkim, and Ghutan, and the descriptions given by the natives of these countries

are strangely alike. The stories relate that the Snowman is a monstrous biped, white-skinned and covered with black hair. According to the natives, the larger examples devour yaks which they disable by hamstringing. Some of the Sherpas of Nepal and Bhutias of Tibet swear to having been chased by these creatures, and lurid pictures of them are to be found in many Tibetan monasteries.

European mountaineers have seen strange tracks in the snow far above the permanent snow-line. Mr. H. W. Tilman, the leader of the 1938 Mount Everest Expedition, has described some remarkable tracks on a snow-field in the Karakorams. They consisted of a line of round indentations the size of soup plates and could not be attributed to otters, birds, or any

of the other creatures that were suggested as having caused them. Strange tracks have been observed by members of expeditions to Kinchinjunga and other peaks. Not long ago, an English lady, Miss Macdonald of Dalimpong, was crossing a high pass into Tibet when she was startled by a terrific roar that shook the ground and was totally unlike the roar of any creature she had heard before. A Polish expedition, investigating these strange tracks, reached a height of 20,500 feet on Nanda Devi in July, 1939, when an avalanche crashed and killed two of the explorers.

WHAT CAUSES GLACIERS

Although the temperature of a high mountain is raised during the day, it drops very considerably at night. On

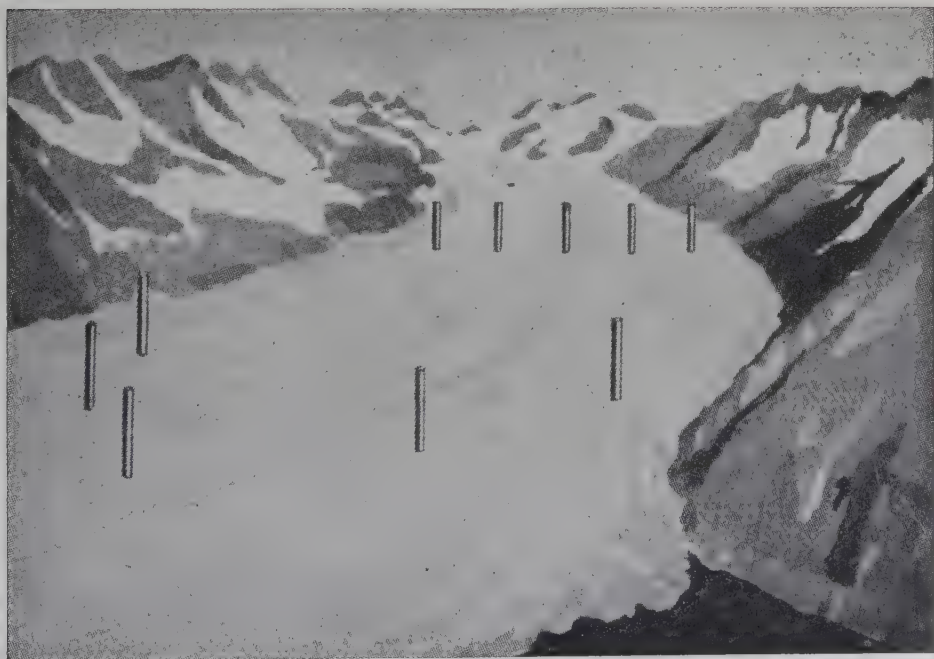


Fig. 17. Showing how the center of a glacier moves more quickly than the sides. After a time a row of stakes originally driven in a straight line would become curved for the center stakes would move more quickly than the outside ones

mountains there is a much greater difference between day and night temperatures than elsewhere. Wherever a great quantity of snowfall gathers in excess of natural wastage, a glacier results. Alternate thawing and freezing of snow, coupled with the constant addition of fresh snow above, causes the lower layers to be compressed into a solid mass. This becomes stratified, the different layers being divided by "dirt-lines," each in-

dicating the previous year's snow on which the wind has deposited dust, leaves, etc. This granular mass is known as *névé* and although not actual ice, it forms the beginning of a glacier. As this ice and snow accumulation increases, its weight pressing downward causes the whole mass to creep down the mountain, ultimately forming a glacier that may extend for scores of miles before it finally reaches a place where it wastes

away faster than it can acquire new ice.

Glaciers move slowly, their rate of travel depending on their thickness, their load of rock waste, the gradient of the valleys or hillsides down which they move, and the temperature of the air. The width of the valleys through which they pass also affects their rate of travel, for a narrow valley constricts the glacier but increases its speed. As in the case of a river, the center parts of a glacier travel more quickly than the sides, being retarded by friction with the sides of the valley (Fig. 17). For the same reason the top part moves more quickly than the bottom, which is in contact with the bed of the valley. In summer the movement is speeded up when some of the ice melts, and the water flowing through cracks in the glacier lubricates the bed over which it is



Fig. 18. The Grosser Aletsch Glacier in the Bernese Oberland, the largest in Switzerland, is 13 miles long and nearly 6,000 ft. broad. Note the medial moraine

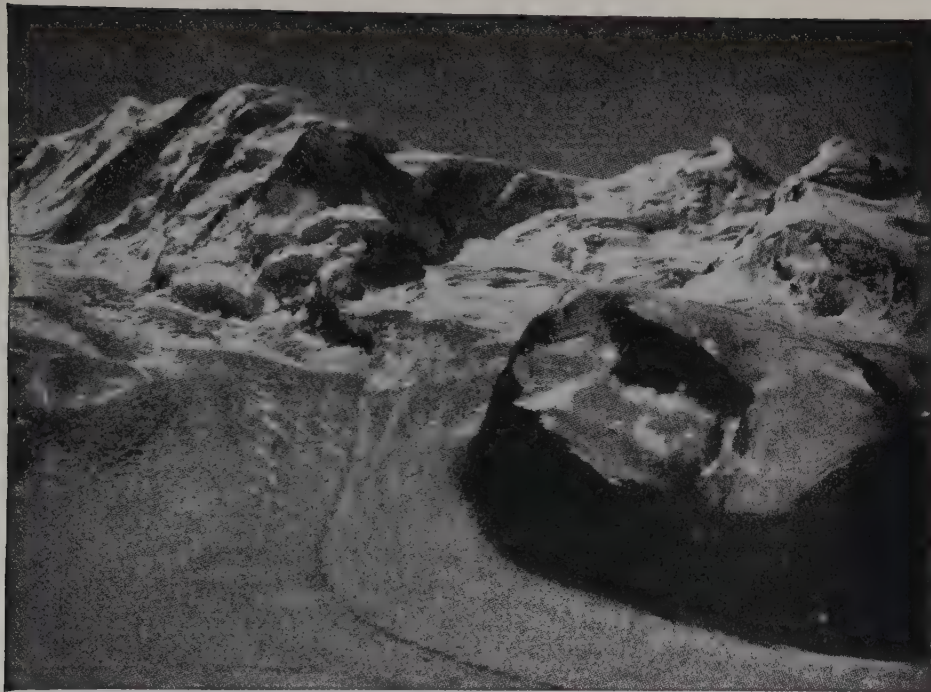


Fig. 19. The Gorner Glacier above Zermatt in Switzerland. The mountain on the left is Tyskamus and the two on the right are Castor and Pollux. Like the Mer de Glace, the Gorner is $9\frac{1}{4}$ miles long. These two are the longest glaciers in the Alps

traveling, so tending to reduce the friction. Glacier ice is able to adapt itself to the windings of the valley down which it flows. The average velocity of the Alpine glaciers is from about 5 to 12 inches a day, or 150 to 360 feet a year. But the rate of movement of the Mer de Glace in the French Alps is from 20 to 27 inches a day at the center, and from 13 to $19\frac{1}{2}$ inches at the sides.

FAMOUS SWISS GLACIERS

There are some 470 large glaciers in Switzerland, the longest being the Grosser Aletsch in the Bernese Oberland (Fig. 18), which is 13 miles in length and 1,968 yards in breadth at its widest part; the Unteraar Glacier and the Gorner (Fig. 19), both 10

miles in length; and the Viescher, nine and a quarter miles in length. The Aar Glacier requires about 133 years to descend the full 10 miles of its length. The movement of the glaciers in the polar regions is generally more rapid than those of the Alps. The Garwood Glacier at Spitzbergen moves 800 feet a month, and the Karajak Glacier (Drygalski) 1,500 feet a month. Jacobshavn Glacier, on the west coast of Greenland, moves from 50 to 75 feet a day; and Upernivik Glacier, 99 feet a day during the summer season.

The relative speed of the Arctic glaciers cannot be due to their gradient, for most of the Alpine glaciers are steeper. It must be due to their great size. Other things being equal,

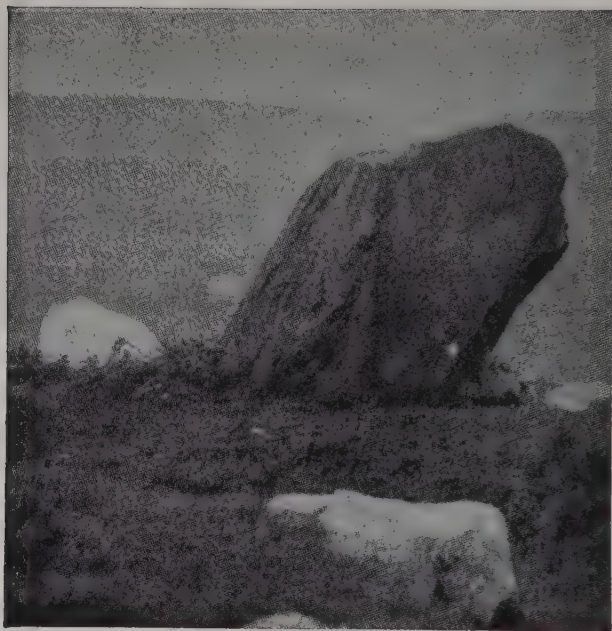


Fig. 20. A glacial erratic, a mass of dark millstone—grit rock lying on local white limestone. This rock was carried here by a glacier many thousands of years ago

a long glacier moves fast at its end. Evidently glacial motion accumulates throughout the length of a glacier, the end velocity being the resultant of all the movements all along the glacier.

The greatest glaciers in the world are found in the polar regions, and besides them the Alpine glaciers fade into insignificance. Over five-sevenths of the whole area of Greenland, about 700,000 square miles, is buried beneath an enormous mass of ice. From it great glaciers, from 2,000 to 3,000 feet thick and over 50 miles in width, creep down the valleys to the sea. Here they terminate in vertical faces from 100 to 1,000 feet in height, from which they break off to form icebergs. On the west of Greenland, at a distance of 130 miles from the coast, there is a solid wall of ice 6,000 feet

in height. Measurements show that over the center of Greenland the icecap is nearly 9,000 feet thick. Northeast Land, Spitzbergen, a broad plateau with an area of 6,200 square miles, is covered by an ice sheet 3,000 feet thick, which is slowly moving to the east, and discharges into the sea as a huge wall of ice, unbroken for a distance of 150 miles. Water from the melting glaciers drains off in rivers loaded with sediment washed out from the ice. Among the notable glaciers of the Arctic is the Great Dove Glacier, 60 miles in width, in Franz Josef Land.

ALASKAN GLACIERS

The great and mighty glaciers of Alaska are world famous for their great size, their speed, the loads they carry, and their response to changing conditions of load and snowfall. The Malaspina Glacier is one of the best known and most spectacular glaciers in the world. Scores of scientists have studied it, and thousands of tourists visit it every summer.

Although ice yields to great pressure, it is not able to withstand tensional stresses, and will break if stretched. In moving through a winding valley there are naturally many such stresses that the ice is unable to withstand, and it fractures. These cracks, which are known as crevasses, generally lie across the direction of flow. Subsequent movements increase

their size, so that one commencing as a mere crack in which it is difficult to insert the blade of a knife, may become a gaping chasm, 1,000 feet in depth. Often these crevasses are covered with snow and so remain hidden. Numerous lives have been lost when mountaineers, failing to detect a crevasse beneath, have fallen to their deaths.

Sometimes the bodies of these unfortunate people have been preserved in the ice and have reappeared at lower levels after an interval of several years. One well-known case was that of Henry Arkwright, who, in 1866, when climbing Mont Blanc, was carried away by an avalanche. Thirty-one years later his body was discovered at the foot of the glacier, having descended over 9,000 feet in the ice in the intervening period. During the following months many of Arkwright's belongings were also recovered from the glacier, including his gloves, tied together with a piece of bootlace, that his sister remembered handing to him before he commenced his fatal journey. His handkerchief and shirt were also recovered, and despite the fact that it had been encased in the ice for thirty-one years, the studs remained in the buttonholes. His pencil case opened as smoothly as on the day he was lost.

GLACIAL MORAINES

Glaciers carry a considerable amount of material along with them, and when this material is carried on the surface it is known as a moraine (Fig. 18). Much of the material comes from the sides of the valley, some being detached by the grinding action of the glacier itself and some falling on to the glacier from the sides above by the action of frost and rain, or more often by the sliding downward of small avalanches of newly fallen snow. When two gla-

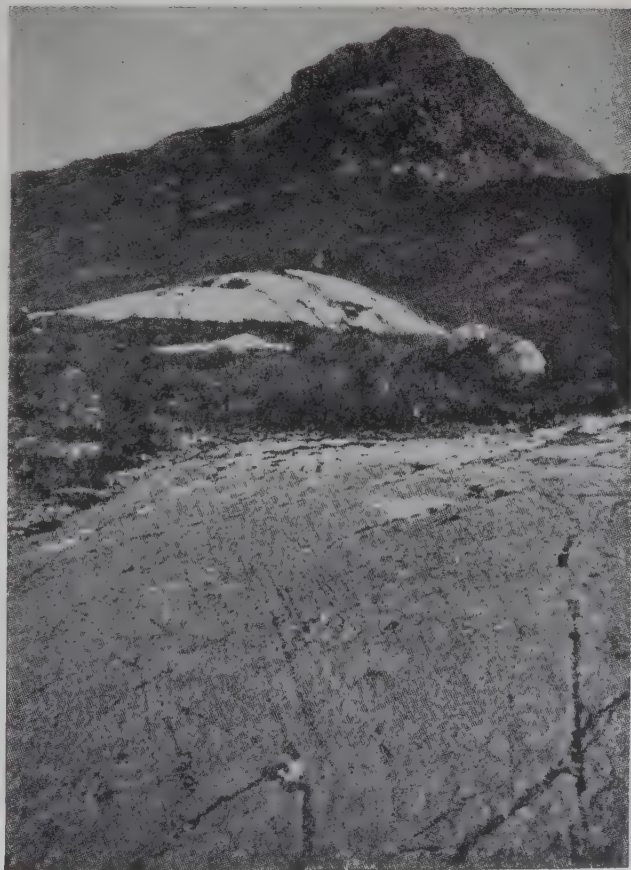


Fig. 21. Scratches on mica-schist rocks in Scotland made by the passage of a glacier in prehistoric times

ciers meet and join together, the right lateral moraine of one and the left lateral moraine of the other unite and form a central, or medial, moraine. By the number of these central moraines on a glacier one can tell how many tributary glaciers have contributed to the main mass. The materials are ultimately deposited at the termination of the glacier, where they form a terminal moraine.

At Clapham, in Yorkshire, there are to be seen large dark rocks of millstone grit standing on the white limestone (Fig. 20). At Cloughmore, in Ireland, blocks of granite rest on a bed of slate. In many other places, too, may be seen large and small rocks lying on strata of an entirely

different formation. The presence of these "erratic blocks," as they are called, is evidence of glacier action in bygone times. They have been carried—often great distances from their parent formation—by a glacier which, when it has melted, has left the erratics stranded in strange surroundings. In many places in this country we can see where prehistoric glaciers have been at work. This is especially true in the northern and mountain states. High mountain slopes, and the bare rock surfaces of the Great Lakes region, offer splendid evidences of glacial abrasion, where rocks bear great cuts and scratches showing that a glacier has passed over them (Fig. 21). From the appearance of the



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Fig. 22. You can almost feel the richness of this soil. This is glaciated land in Columbia County, Wisconsin. The enrichment and leveling of much of the Middle West by glacial action created one of the greatest stretches of good farm land

scratches we can even determine the direction in which the glacier was moving.

DENUDATION

Glaciers play an important part in the work of denudation, grinding away the land and scouring out valleys. We can always tell that a glacier has been at work, for glaciers scour out the valleys with a U-shaped cross section, whereas streams cut their valleys V-shaped.

This graphical summary of the processes of a valley glacier, resembles in a small way the activities of a great continental ice sheet. A huge ice sheet, like that which now covers Greenland, formerly spread over the larger part of the northern Mississippi Valley, and far beyond it to the East. The wastage which this enormous glacier left behind in Iowa, Illinois, Indiana, Ohio, and western New York,

created an expanse of freshly ground rock materials. Upon this deposit was later developed the greatest stretch of good farm land in the world.

The rocky stretches of Minnesota, Wisconsin, Michigan, and Ontario, provided material which enriched the lands farther south. The distribution of this rock material leveled off valleys and hills, creating a plain surface convenient for cultivation. In places the leveling was so well done that artificial drainage is absolutely necessary. But the land has been so productive and the markets so good, up until about 1929, that the whole Middle West has been persistently prosperous. Even today, in spite of the stagnation of world markets, the Middle West can get along comfortably and feed itself and millions of other people besides, from its rich and well-cultivated acres of glaciated land.

CHAPTER 10

THE ENVIRONMENT OF MAN

THE earth on which man has to make his home provides a rocky foundation for all man's structures. This foundation we call the crust of the earth. It is that part which is exposed to our direct observation, to our exploration by mining and drillings, and from which we gather all our mineral resources.

The crust is composed of three main classes of rocks. They are called igneous, sedimentary, and metamorphic. Igneous rocks were, as their name implies (Latin: *ignis*, fire),

formed at high temperatures. They are supposed to have solidified by crystallization, or part crystallization, from a molten state. It is supposed that the minerals of which they are composed were mutually dissolved under the conditions of high temperature which caused them to become liquid. It is true that the number of minerals found in these rocks is limited to about twenty common minerals, such as quartz, various feldspars, amphiboles, pyroxenes, micas, magnetite, and olivine. About a dozen



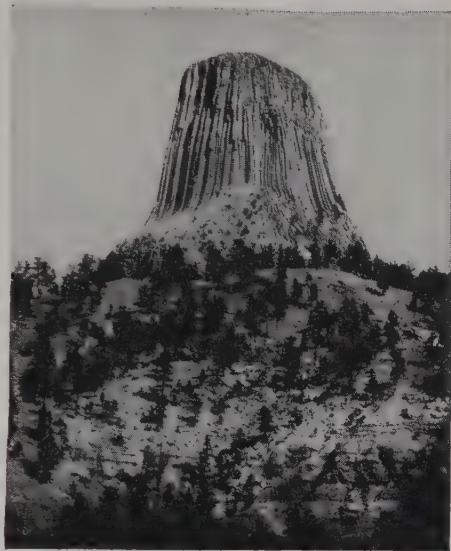
U.S. Geological Survey

Fig. 1. A massive granite outcropping at Sylvan Lake, in the Black Hills of South Dakota. Granite is an igneous plutonic rock

other minerals are less common, and others are definitely rare in igneous rocks.

In most cases the crystals are less than one-half inch in diameter. Occasionally large crystals, several inches long, are found in igneous rocks. Ordinarily very large masses are of uniform sized grain in the interior, but tend to have coarse crystals at their margins. Although rate of cooling by no means is the sole control of the size to which crystals grow in an igneous rock, it is one factor. Certainly lava which cools very quickly at the surface of the earth is likely to be glassy, that is without any crystals, or having only very small crystals. The best-known of the igneous rocks probably is granite, which is usually of moderate grain size, and composed essentially of the minerals quartz, feldspars, and mica.

There are two kinds of igneous rocks, plutonic and volcanic. In Greek mythology Pluto was the god of the underworld, and the rocks found at great depths below the earth's surface have been called plutonic after him. They generally consist almost entirely of well-defined crystals, packed closely together because of the pressure at the great depths at which they were formed. Granite (Fig. 1) is a typical example of plutonic rock. The second kind, called after Vulcan, the god of fire, is formed near the earth's surface, or perhaps forced through the earth's crust by volcanic action. Basalt (Fig. 2) is a good example of the volcanic rocks, which are composed partly of crystals and partly of a kind of glass. Their rate of cooling was much more rapid and did not allow all the molten material to turn completely into crystals.



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Fig. 2. Devils Tower, an outcropping of igneous rock in Cook County, Wyoming

SEDIMENTARY ROCKS

Leaving now the fire-formed rocks we come to the sedimentary rocks (Latin: *sedere*, settle), formed from sediment washed down by rain and water, and deposited, in prehistoric times, at the borders of what were then seas. The particles composing this sediment settled down in the sea and formed layers, or strata, of rock (Fig. 3). Sometimes these stratified rocks are composed of the remains of living organisms that once inhabited the seas. When these creatures died their bodies and shells sank to the bottom of the ocean and formed these deposits. These marine animals were so numerous, and the times during which they persisted were so long, that many of these deposits are hundreds of feet thick, and some of them reach thousands of feet in thickness. Limestone is sediment which is built up of the remains of extinct animals.

Even today the formation of coral reefs—a kind of limestone—is going on, for large colonies of tiny creatures extract the mineral matter in sea water and build it into hard skeletons that act as a foundation for other

The third type of rock, the metamorphic (Greek: *meta*, change; and *morphe*, form) originally belonged to either the igneous or the sedimentary class. Having been subjected to intense heat or pressure, it has under-



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Fig. 3. The Grand Canyon of the Colorado River displays layer upon layer of stratified, generally fossiliferous rocks. View is looking west from Point Sublime

corals to build on. Thus a coral reef is formed, the sea depositing carbonate of lime between the individual skeletons, so that eventually the whole forms a compact mass of rock. Sometimes the particles are cemented together by mineral matter deposited at the same time, or introduced later by percolating water. In sandstone rocks, for instance, the quartz grains are cemented by carbonate of lime, oxides of iron, and other substances that add color to the deposits, so that we have yellow, brown, red, or even green sandstones which give rise to many beautiful formations.

gone a complete change so that its original features have been obliterated. Mud deposited at the bottom of the ocean normally becomes a solid mass of clay or shale, but if subjected to great pressure it becomes hardened and changes into slate. Similarly, by intense heat or pressure the igneous granite may be changed into metamorphic gneiss; sandstone into quartzite; limestone into marble; and bedded sediments into gneiss (Fig. 5).

It is of such materials as these that the earth's crust is composed. There are scores of differently named rocks, including the various sands, clays, and

gravels, but all belong to one or other of the three great classes we have mentioned above.

UPLIFTING OF OLDER ROCKS

It is perhaps fortunate that there have been considerable movements in the crust. If this had not been so we should not know very much about the older rocks, for in the ordinary course of events they would lie far below the more recent rocks. These earth movements, and the denudation — or washing away by rain and other agents — of the surface rocks have resulted in some of the

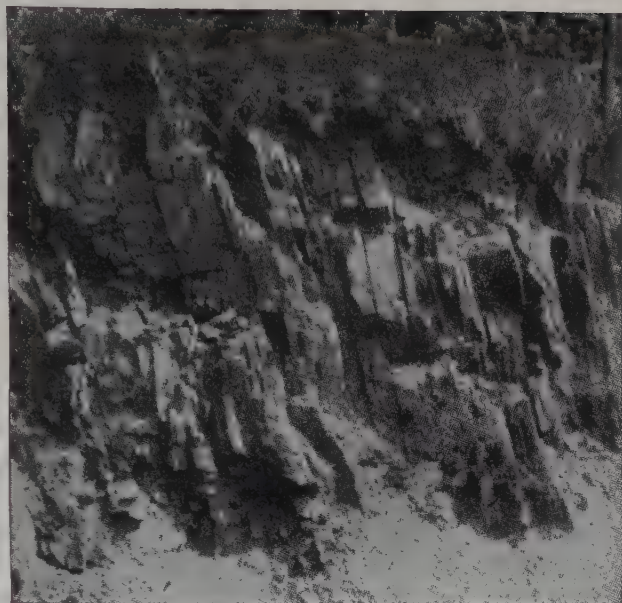


Fig. 4. These almost vertical layers of shale rock were once horizontal layers of clay. They assumed their present position through movements of the earth's surface



Photo by T. T. Quirke

Fig. 5. Metamorphic rock is characterized by a gneissose texture, shown by the bands and stripes. This formation is near Bigwood, Ontario

older rocks being exposed at the surface in some places. For instance, on Mount Rushmore, Pike's Peak, El Capitan, or Stone Mountain, we see granite (Fig. 1), and this we know is a plutonic rock cooled at a great depth below the earth's surface. That it is now found at the surface does not indicate that it has been formed there; its presence is due to the fact that it has been lifted by earth movements and that the overlying material has been removed by denudation.

Sometimes, as a result of these earth movements, sedimentary rocks have been tilted from their original horizontal position and now lie at an angle, or "dip," inclined more or less to the horizontal (Fig. 4). Sometimes the enormous pressure arising out of the movements has caused rocks to be bent or folded over or around other rocks, giving the strata an arched appearance. Some good examples of such folding are to be seen in the bedded rocks exposed in railroad and highway cuts in the Appal-

lachian Mountains, in many places in California, and in the mountains of the arid Southwest, where rock outcrops are kept free of mantling vegetation. Fig. 6 illustrates diagrammatically how what was originally a level layer of rock on the bed of the sea may be first arched and finally eroded into jagged mountain shapes.

Despite the alterations, caused by earth movements and denudation, in the original order of the rocks, it is possible to identify the period to which they belong by the fossils they

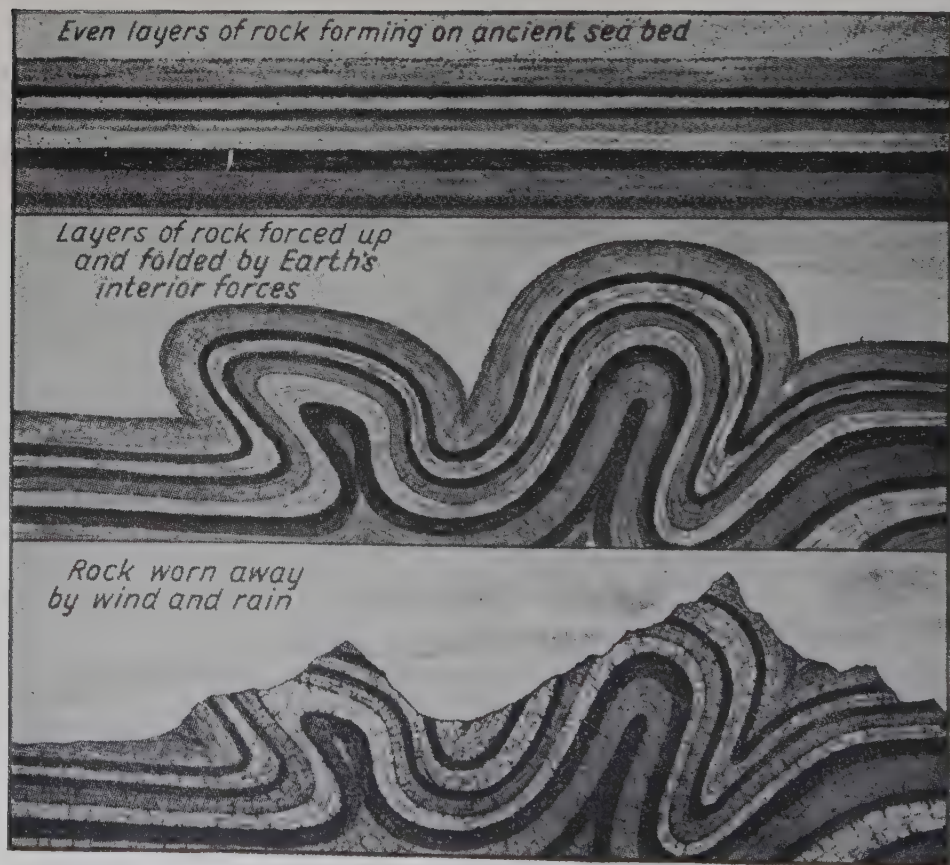


Fig. 6. How mountains are formed. In prehistoric times they formed part of the ocean bed; then movement of the earth's crust forced them upwards, to be worn away later by the weather

contain. A fossil may be either the actual remains of some animal that lived in a bygone age and was trapped in the rock when it was being formed, or it may be the imprint of an animal or plant preserved in the rock. Each stratum of rock has its own particular fossils, and similar fossils are found in rocks of the same age in all parts of the world. Fossils do not enable us to tell the actual age of the rocks in which they are found, but they do give us some idea of their relative ages. In the oldest rocks there are no fossils, for life did not exist on the earth at the period when they were formed.

FOSSIL STORIES

The earliest known forms of life are preserved in rocks which originally were mud, sand, and lime rock. All of these were deposited under water, presumably in sea water. It follows that the fossils preserved pertain to marine or fresh water animals. It is quite possible there was contemporaneous life upon the land but no land deposits of that age have yet been found with fossils. We may say that the oldest known forms of life lived in water, and probably in sea water.

One amazing feature of the early forms of life is their variety. All the major divisions of the animal kingdom except the vertebrates are known to have been contemporaneously represented at very early ages. Some of the most ancient fossils have not yet been completely worked out in terms of biology. We have to rely upon comparison with living examples of the same class in order to form an opinion as to how the original animal lived and used its specialized organs. If there are no close relatives of the extinct creature among living forms,

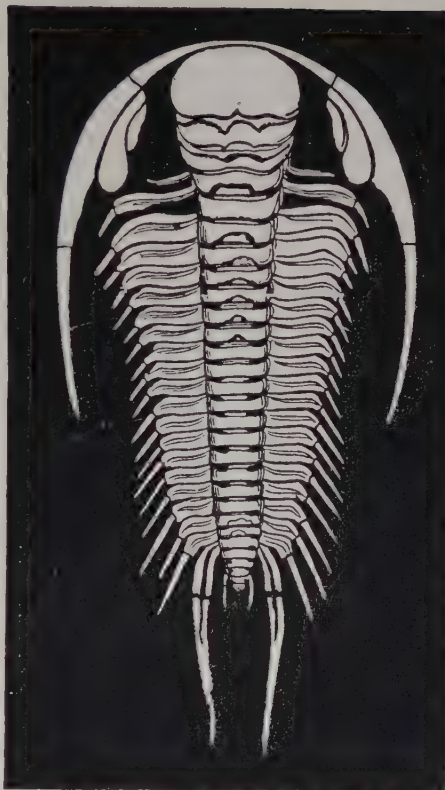


Fig. 7. Fossilized remains of a Cambrian Trilobite, one of the earliest forms of life

we are quite in doubt as to its place or function in its environment and as to its significance.

One of the early forms of unknown relationships is known as graptolites (Greek: *graptos*, written; and *lithos*, stone) because they have the appearance of writings or drawings on stone. Graptolites are thought to have lived as floating colonies with highly specialized and sharply localized special organs. How so much specialization could have been developed by an early form is a mystery. Other early forms include corals, crinoids or sea lilies, and trilobites, which were some-

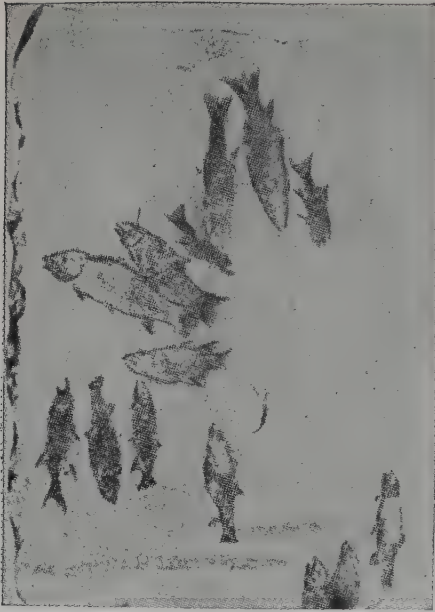


Fig. 8. Fossil fish, millions of years old. The delicate markings of the scales have been perfectly preserved. These fish lived in the Triassic Age

what like the king crabs of today (Fig. 7). The trilobites also show an elaborate and highly specialized de-

velopment, which appears to require a very long period of earlier evolution from simple forms. The suddenness with which highly developed classes of animals appear early in the geologic record seems to imply that much earlier records some day may be discovered. In later rocks fishes appear, at first shellfish more or less shrimplike, and then true fishes which begin to occur in increasing numbers (Fig. 8). Fishes are vertebrates, and as such they are definitely related to all those forms which we class as the higher animals, including man. It is worthy of note that in the records of very early life there are no vertebrate fishes.

INTERPRETING THE FOSSILS

The position of rocks in layers, with the oldest at the bottom and the youngest above, makes it possible for us to arrange the enclosed fossils in the chronological order of their deposition. This is how the time element is brought into the theory of biological evolution.

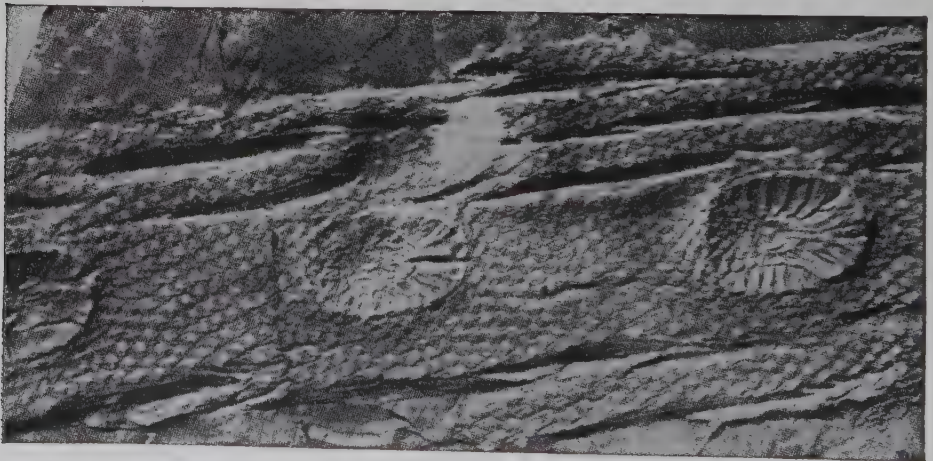


Fig. 9. A beautifully preserved fossil of a scaly tree, the *Lepidodendron Velthmainum*. Substances with soft structures such as plants, have been preserved where pressure has been gradual

No successful understanding of the fossil forms is possible if the rocks have been so severely folded and sheared that the fossils have been destroyed. Where rock pressure has been moderate, animal and plant remains have been perfectly preserved in a marvelous way. Not only does this apply to hard objects, such as shells and bones, but to the scars or rugosities on shells or bones indicating where muscles or fleshy parts of the animal are attached which could not otherwise be preserved in a fossil. Hard fruits, like pine cones, bark, and leaves of plants, leave excellent fossils (Fig. 9).

Even spores of ferns (Fig. 11) and pollen grains have left a perfect record in the rocks. Ripples formed by the sea in the sand, footprints of prehistoric monsters, and even the imprints of raindrops (Fig. 10) are conserved and give up their secrets to the inquirer into the marvels and mysteries of science.

COMING OF THE AMPHIBIAN

Limitations of space prevent us from making more than a brief reference to some of the more interesting of the creatures whose remains have been found in the rocks. It would appear that the earliest forms of life were algae, followed by crustaceans, and then by fish. After these came the amphibians—creatures that were capable of living both in the air and in the water. At one time these were abundant, but they are now nearly extinct, being represented only by the frogs, toads, newts, and salamanders.

The amphibians were followed by giant reptiles—the saurians or lizard-like creatures. Of these the commonest appears to have been the *Ichthyosaurus*, or fish-lizard, which some-

times grew to be as large as a whale, with its four swimming paddles, and long pointed tail (Fig. 12). Its enormous eyes were protected by bony plates and some 200 teeth adorned its alligatorlike jaws. Fossils of *Ichthyosauri* have been found all over the world in great numbers, and are plentiful in western Europe.

Another reptile of a similar type was the *Plesiosaurus*, with body and tail like those of a quadruped and a long neck, at the end of which was a small head. It was able to move



Fig. 10. Prehistoric raindrops. These fossilized impressions were found in sandstone rocks that form part of the seashore millions of years ago

quickly through the water by means of four large paddles, which in some cases have been found to be over seven feet in length. Fossils of *Plesiosaurs* have been found at Ely, in England. This creature has been of special interest recently because it has been suggested that the far-famed "Loch Ness Monster" may be a living example of a *Plesiosaurus*, a surviving link with those prehistoric times. If this is the explanation of the mystery of Loch Ness, perhaps there is more than one "monster" and perhaps these creatures have managed to breed and survive in the 900-foot deep Scottish loch, where subteranean caves deep

down in the waters of the lake give access to the sea. Whatever the "monster" may be, it seems established that, if it exists at all, it is an amphibian, that is to say, it breathes air with lungs and can equally "breathe" water with gills. There is certainly some similarity between the prehistoric *Plesiosaurus*, and the sketches and descriptions of the "Loch Ness Monster."

Until some actual specimen of the creature can be captured, either dead or alive, scientists will examine all reports with sympathy, but with little enthusiasm. That even a small number of otherwise extinct dinosaurs

exists anywhere is highly improbable. It is much more practical to explain the reports of an alleged sea monster on some other basis.

THE HUGE DINOSAUR

Other great creatures lived entirely on the land. The dinosaurs—terrible lizards—form a large group of *sauria*, many of great size and with a wide variety of form. Large numbers of fossil dinosaurs have been discovered in Utah, Wyoming, Kansas, and Colorado, in Tanganyika, in the Gobi Desert, and elsewhere. One such huge creature was the *Diplodocus*, examples of which have been found measur-



Fig. 11. A remarkably well preserved fossilized fern

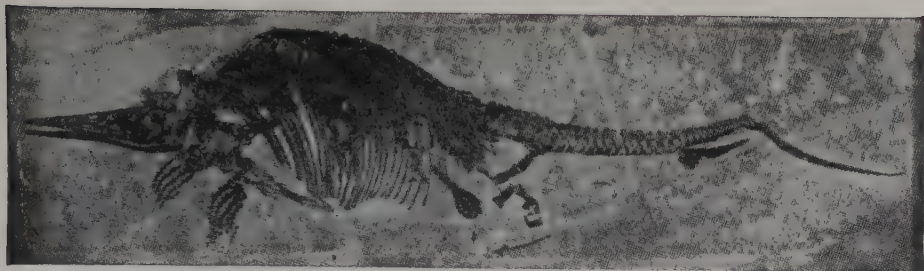


Fig. 12. A fossilized Ichthyosaurus, with embryo of young inside. This creature was a great fish-lizard, a long extinct marine reptile that measured 40 feet in length

ing up to 80 feet in length. Then there was the terrible *Allosaurus* that resembled a giant kangaroo with crocodile's teeth, and a head as large as that of a horse. This ferocious creature, which walked on its hind legs, lived on the herbivorous dinosaurs and probably exterminated them. One of the largest creatures that has inhabited the earth was the *Brontosaurus* or Thunder Lizard. It measured over 90 feet in length, stood 15 feet in height, and weighed 40 or 50 tons. Another huge lizard was the *Iguanodon*, with birdlike feet, the thumb being in the form of a huge spur at right angles to the palm. Strange to say, these creatures had very small heads and brains which were small even for their small heads. They must have been dull-witted creatures, very slow in response to their sense perceptions. The burden of providing for so large a body must have been a severe tax on so small a brain!

All these creatures lived a very long time ago—perhaps 30,000,000 years—and after inhabiting the earth for, perhaps, 20,000,000 years they became extinct. They were followed by the mammals, which became dominant in a comparatively short time.

The mammals may have emerged from the amphibian and reptilian as-

semblage through the marsupial transition stage. Certainly there were marsupial forms contemporary with the most ancient mammals, and considerably younger than the ancient reptiles. In any case mammalian forms appear to have originated from similar reptilian types. The sea-swimming reptiles probably gave rise to the whales. The great lizards never advanced to mammalian form, and remain today as alligators and crocodiles. Free-running reptiles of long-legged type appear to be ancestral rhinoceroses, and to have provided the origins of primitive horses. Somewhere in the reptilian groups were the ancestors of the flying foxes, lemurs, and the anthropoid apes. Little as we can state with assurance about the beginnings of the human race, we can be assured that it will ultimately be found to be involved in the highly complex transitions and relationships of the creatures of Tertiary times. Fascinating as is the study of the life record in all its phases, that study becomes arresting, dramatic, and vital when we apply it to the rise of man himself. Except for the ever-continuing efforts of man in conducting scientific study, the earth's story could never have been told, and without man himself it could have neither point nor conclusion.

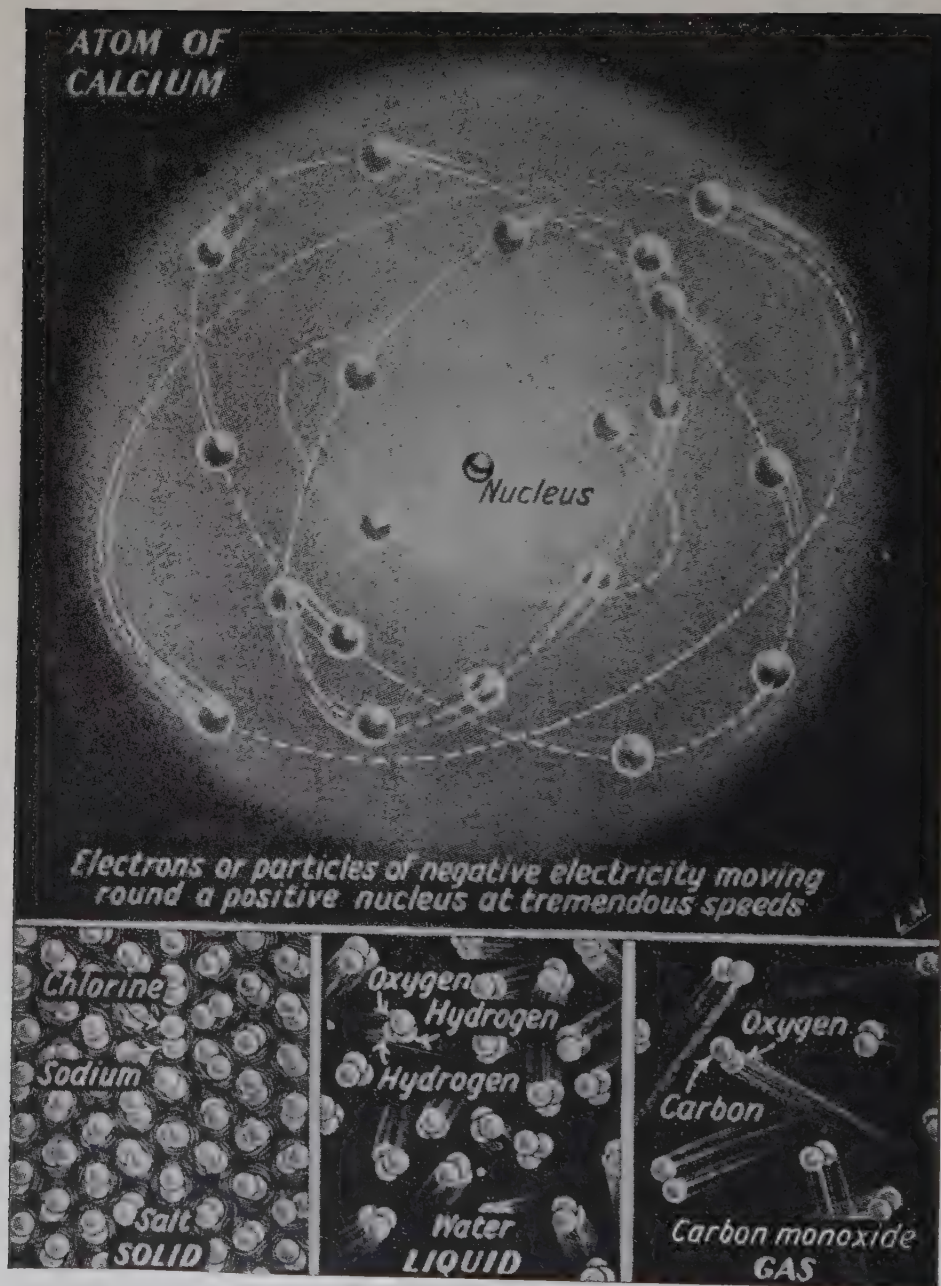


Fig. 1. Imaginative pictures of the atom and the molecule. An atom consists of one or more negative electrons revolving round a positive nucleus. A molecule consists of two or more different atoms. The lower pictures show the molecules of a solid, a liquid and a gas

SECTION III

THE NATURE OF MATTER AND ENERGY

CHAPTER 11—THE IMPORTANCE OF MOLECULES AND ATOMS

CHEMISTRY is the branch of science which studies the materials of which the universe is built. It has been in large measure responsible for man's increasing mastery over these materials and, indeed, for the comforts of our modern civilization. It is well to emphasize that chemistry deals not only with such rather rare materials as dyes, drugs, and perfumes; but also with such essential but perhaps less romantic substances as steel, glass, bricks, cement, plaster, paints, soap, gasoline, fertilizers, and a host of others without which civilized living would be impossible. Nor are the materials which make up living organisms and their changes, which constitute life itself, beyond the scope of chemistry. For these and other reasons this science offers interesting facts and theories for study to the person who takes pride in being well informed.

The practical achievements have been amazing but they could never have been accomplished if there had not been developed theories of the structure of matter which guide chemists to the successful solution of their problems. For research is little better than a random groping in the dark, and discoveries are few and completely accidental when theory is lacking. Thus the theory of the structure of matter which we are about to discuss has been of the greatest practical value. It has led and is still

leading chemists to remarkable discoveries. The study of this theory is interesting and absorbing, for it leads to the discovery of a host of sub-microscopic particles, the acts of whose existence explain the drama of the visible material universe.

CHEMICAL ELEMENTS

Modern chemistry began when Robert Boyle (1627–91) stated, for the first time, the definition of a chemical element as we recognize it today. An element is composed of one kind of matter and can neither be broken up into simpler substances nor built up from simpler substances. Now it is impossible to tell by merely examining a sample of a pure substance whether it is an element or not. For example, pure sugar appears homogeneous even under microscopes of the highest possible magnification; that is, every crystal is exactly alike. They are all equally transparent and each has the same geometric form. Even the angles between crystal faces are identical. Of course, some are larger than others, but size is of no significance in this connection. However, if we put these crystals to the test of an increased temperature, a change is soon apparent. Water vapor is given off and a char or carbon is left behind. Obviously sugar cannot be classified as an element for it has been decomposed into simpler substances. Water, as we have seen, is no

element, for when an electric current is passed through this substance, hydrogen gas appears on the surface of the metal electrode connected to the negative pole of the source of current and oxygen appears at the positive electrode.

Chemists today recognize the existence of 90 elements which have resisted all attempts to decompose them into simpler things. They also realize that two elements at least remain to be discovered and are able to describe in some detail what the properties of these missing elements will be! The elements are classified as either metals or non-metals. The more familiar metals may be recognized by their names; those less familiar, have names ending in "um." Although some 90 elements exist, only a small fraction of this number are at all abundant. The twelve elements of Table I make up over 99 per cent of the earth's crust and the atmosphere. The first two alone, oxygen and silicon, makes up three-fourths of that portion of the earth in which we live.

considered as museum specimens but have since become very useful indeed. Aluminum was once used for jewelry! (Fig. 2)

CHEMICAL COMPOUNDS

These elements combine with one another to form compounds. When they do so an astonishing change in properties takes place. The properties which characterize a compound are in no sense a combination of the properties which its constituent elements show in the free state before combination has taken place. For example, the metal, sodium, is a dangerous substance to handle. When thrown into water a reaction of explosive violence takes place. The element, chlorine, is a greenish-yellow gas which is so highly poisonous that it has been used in gas warfare. Yet the compound of these two elements is common table salt used in the average home. Several hundred thousand compounds exist of which the majority, perhaps, do not occur in nature but have been synthesized in the laboratories of research chemists.

TABLE I—RELATIVE ABUNDANCE OF THE ELEMENTS

Oxygen	49.2%	Potassium	2.4%
Silicon	25.7%	Magnesium	1.9%
Aluminum	7.4%	Hydrogen	0.9%
Iron	4.7%	Titanium	0.6%
Calcium	3.4%	Chlorine	0.2%
Sodium	2.6%	Phosphorus	0.1%

The relative abundance of an element, however, is not always an indication of its importance. Carbon, for example, does not appear in the table. Yet it is an essential element in the organic compounds of which living organisms are composed. Many elements when first discovered were

STRUCTURE UNITS

As yet nothing has been said of the theories of the submicroscopic structure of matter. The clue to the existence of structure particles lies in the fact that when different samples of a pure compound are analyzed the con-

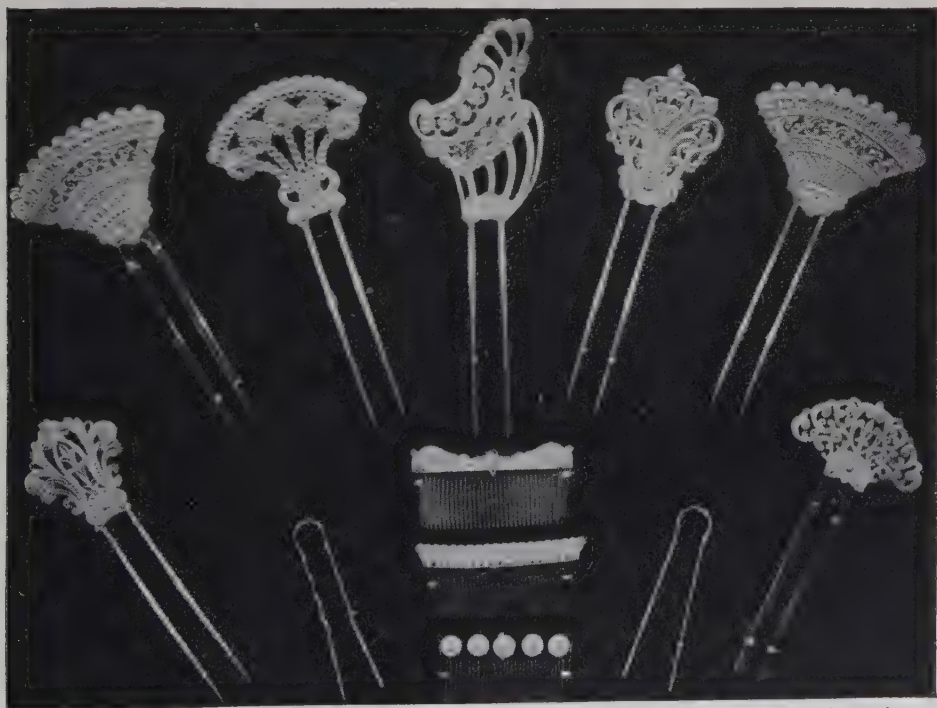
stituent elements are always found combined in the same proportions by weight. For example, every sample of pure water, no matter what its source, is by weight composed of 88.81 per cent of oxygen and 11.19 per cent of hydrogen.

This so-called law of constant composition led William Higgins and John Dalton at the beginning of the nineteenth century to postulate that each element is made up of submicroscopic particles called atoms; that the atoms of a given element are identical and possess a characteristic weight; and that there are as many different kinds of atoms as there are elements. These atoms in turn combine to form

molecules (Fig. 4). When atoms combine to form the molecules of a given substance the same number of each kind are found linked together within each molecule. Every water molecule is made up of one oxygen and two hydrogen atoms (Fig. 3). Since the oxygen atom weighs 16 times as much as the atom of hydrogen, the weight proportion of hydrogen to oxygen in every water molecule must be as 2 is to 16, or 1:8. Thus the definite composition which characterizes each compound is explained.

STATES OF MATTER

One of the first properties to be observed when a sample of matter is



Aluminum Co. of America

Fig. 2. These back combs, side combs, and hair pins, all made of aluminum, were worn with pride by milady back in the days before chemistry and Charles Martin Hall discovered a method by which aluminum could be made inexpensively and therefore used for wide range of commercial products

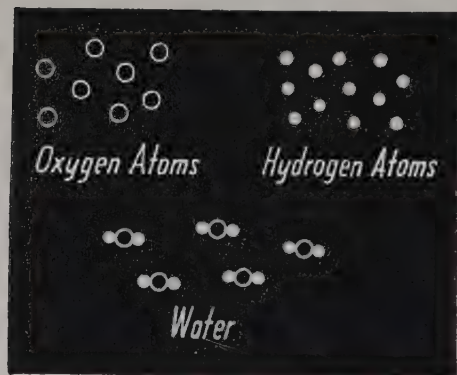


Fig. 3. Two hydrogen atoms and one oxygen atom combine to form a molecule of water, symbolized in a chemical formula as H_2O

examined is the state in which it exists under ordinary conditions. Some substances are solids, others liquids, and still others gases. Of course the temperature is the most important factor in determining the state in which a given substance exists. Below $32^\circ F.$, or $0^\circ C.$, water is a solid and above $212^\circ F.$, or $100^\circ C.$, this substance becomes a gas. To the Eskimo ice is the common form, whereas to a hypothetical asbestos creature on the surface of a much hotter planet than our own, water would normally be a gas. The state of a substance under a given set of conditions is determined by forces of attraction which exist between its molecules. If such forces did not exist, all substances would be gases which could not be liquefied no matter how low the temperature. However, the strength of these forces between the molecules of a given kind of substance are characteristic of the substance. If they are weak, the substance is a gas. If they are moderately strong, the molecules are pulled closer together and the substance is

a liquid. If they are very strong, the substance is a solid.

In a gas the comparatively weak intermolecular forces cannot prevent the molecules from diffusing away from one another to fill any container, no matter how large, in which a gas sample is placed. Furthermore, the space between the molecules of a gas is so great, as compared to the size of the molecules themselves, that gases may be compressed with comparative ease. In liquids these forces are great enough to pull the molecules much closer together and to hold them to a definite volume. A gallon of gasoline does not expand to fill the gas tank. For this reason liquids show a free surface. In solids the molecules are arranged in a regular space pattern, the existence of which we can readily recognize by the crystalline forms which characterize the solid state. The molecules are literally frozen in a symmetrical pattern in space.

A chemically uncombined element is composed of atoms of the same kind. In the solid state these are ar-

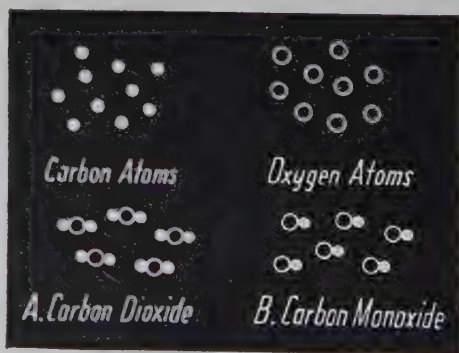


Fig. 4. (A) Two oxygen and one carbon atom combine to form carbon dioxide. (B) One oxygen and one carbon atom combine to form the deadly gas, carbon monoxide

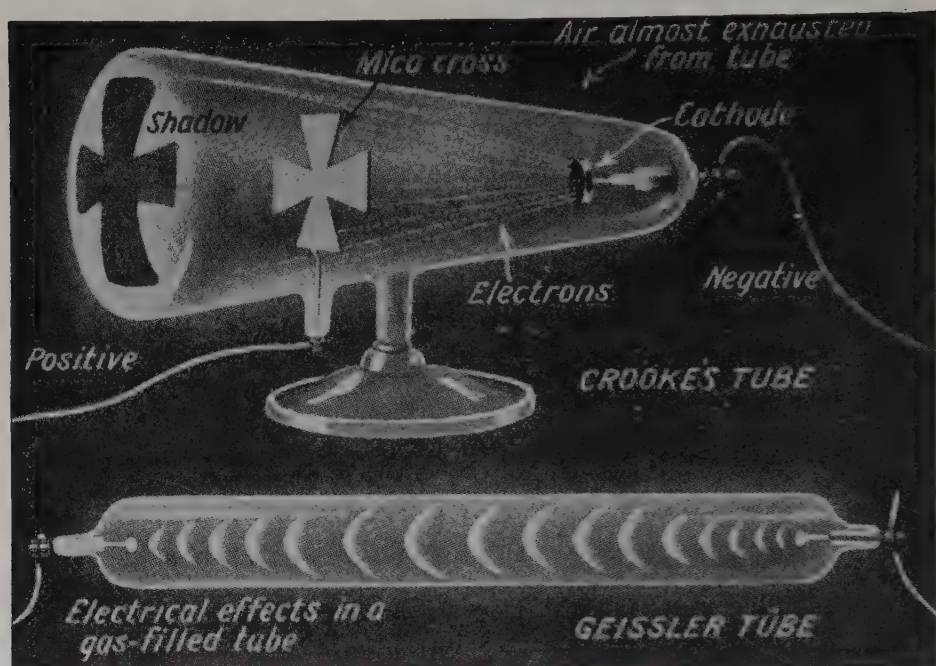


Fig. 5. Sir William Crookes discovered that when an electric current was passed through a tube almost empty of air, rays crossed the tube which made the air luminous. These cathode rays resemble light in that an opaque object (Maltese cross in diagram) introduced in their path causes a shadow. Unlike light rays, cathode rays are sensitive to a magnet

ment has strikingly similar properties. In other words there is a periodic recurrence of elements of nearly the same properties. By arranging the elements in rows of eight those which are alike are in the same vertical group. Such a periodic table has been a great help to chemists for it has helped them keep in mind a vast amount of information. Each group of elements is characterized by a set of properties so that it is unnecessary to keep in mind the properties of each of the 92 elements.

This periodic relationship was a clear indication that, as the atoms became heavier, similarities in *structure* must reappear regularly to explain the recurrence of elements of

similar properties. If atoms have a structure, there must be *particles smaller than atoms* to serve as structure units! These subatomic particles, of which the atoms of all the elements are composed, were discovered by physicists within the last 40 years.

SUBATOMIC PARTICLES

The first of these particles to be discovered made its presence known in a somewhat spectacular fashion. It is difficult to get an electric spark to jump between electrodes which are separated by a distance of more than a few inches. This is because of the resistance which air at ordinary pressure offers to the passage of electricity. However, if the electrodes are

sealed into the opposite ends of a glass tube from which the air has been almost completely evacuated, an electrical discharge may be readily obtained with the aid of a small spark coil. The atoms of nitrogen and of oxygen left in the tube glow with characteristic colors. Indeed the chemical nature of the gas left in the tube determines the color of the light emitted. The use of such tubes in advertising signs is well known (Fig. 6). The red light of neon atoms, the yellow-pink of helium, and the greenish-blue of mercury vapor are familiar. Combinations of gases together with the use of fluorescent glasses are used

to provide other colors. Thus a mixture of argon gas and mercury vapor in a clear glass tube emits an intense blue light, whereas neon in fluorescent glass tubes may be used for pink or orange. A "noviol" (green) glass tube filled with an argon-mercury mixture glows with a bright green color.

Spectacular though these color effects may be, their production is a secondary effect produced by the bombardment of the gas atoms by *subatomic* particles emitted from the cathode, or negative pole (Fig. 5). The nature of these cathode rays was revealed in 1897 by the brilliant research of the late Sir J. J. Thomson,



Copyright Ewing Galloway

Fig. 6. Many different gases, contained in glass tubes, are used for lighting purposes. Neon signs are a familiar example. The tubing units above, however, have been filled with hydrogen gas, which provides a light almost exactly like daylight.

Note the reflector behind the unit in the right foreground

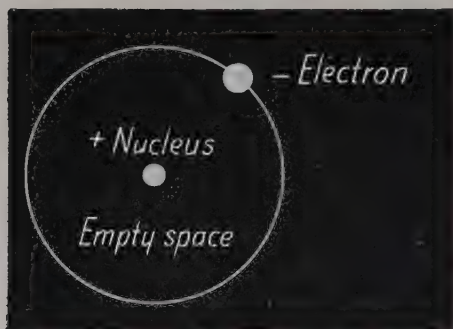


Fig. 7. How the electron revolves round the positive nucleus in the hydrogen atom

then director of the Cavendish Laboratory of Experimental Physics at Cambridge. He found that these rays are composed of swiftly moving, negatively charged particles, each of which is nearly 2,000 times lighter than a hydrogen atom. Since this atom is the lightest of all the atoms, a subatomic particle had been discovered. It is called the *electron*. Shortly thereafter it became apparent that electrons are universal constituents of all atoms. The cathode of the discharge tube may be made of any metal but the properties of the electrons which it emits are the same. Edison discovered that they are emitted from the incandescent filaments of light bulbs, a discovery which marks the first step in the development of the radio-tube. Hot metallic oxides emit electrons. They appear when metal surfaces are illuminated with either X-rays or ultraviolet light. Finally the beta rays which accompany the disintegration of certain radioactive elements are electrons. These particles then must be considered as structure units in the atoms of the elements.

THE PROTON

As atoms are uncharged when they are uncombined, it became obvious

that they must contain charges of positive electricity to counterbalance the negative charges on the electrons in their structure. Rutherford, the late, great physicist, who succeeded Thomson in the directorship of the Cavendish Laboratory, was able to prove that these positive charges are concentrated in a nucleus in the center of each atom; and that most of the weight of the atom resides in this nucleus. The hydrogen atom (Fig. 7), the simplest of all, is made up of one electron and a nucleus of a single positive charge equal in magnitude to the negative charge on the one electron. Until quite recently this singly charged positive nucleus of the hydrogen atom was the lightest known particle bearing a positive charge. It is called a *proton* and is a constituent of the nuclei of all of the atoms of the 92 elements. Since an electron weighs only $\frac{1}{1800}$ as much as the hydrogen atom, and the proton is the only other material particle in this atom, practically the entire weight of the atom is due to the presence of the proton in the nucleus.

The number of protons in the nucleus of an atom determines the element to which the atom belongs. Fur-

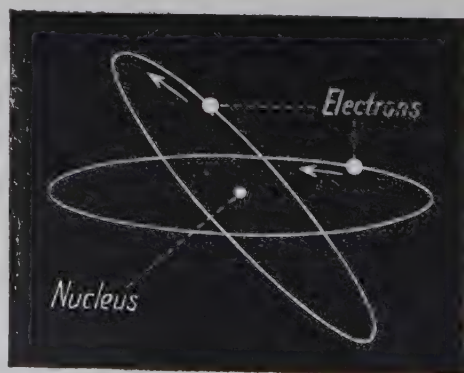


Fig. 8. Disposition of electrons in an atom of helium—one of the simplest atoms

thermore, this number is the same as the order number of the element in the periodic table; that is, the number which is assigned to each element when they are arranged in the order of their increasing atomic weights. Thus hydrogen has an atomic number of 1 and uranium, the element whose atom is the heaviest, an atomic number of 92. The uncombined atom of an element is electrically neutral. Hence the number of electrons must

real meaning, it is apparent that these tiny atomic solar systems are mainly space and that the electrons and the nucleus take up only a minute fraction of the space of the atom as defined by the orbit of the most remote planetary electrons. Since atoms make up molecules and molecules in turn the larger masses of matter, the material universe must be mainly space, studded at intervals with almost an infinite number of infinitesimal elec-

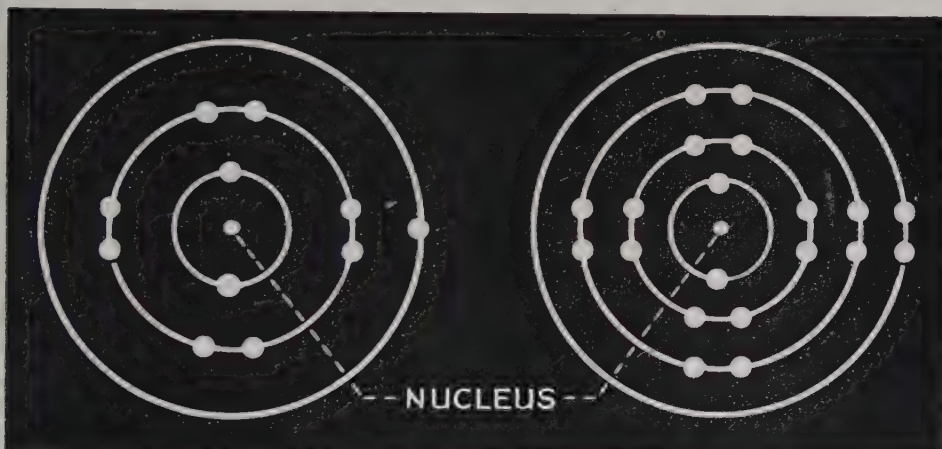


Fig. 9. On the left side is an atom of sodium, on the right an atom of calcium

be equal to the atomic number of the element also. The weight of these electrons, as we have said before, is almost negligible as compared with the relatively more massive nucleus. Since oppositely charged particles attract each other, these electrons are held within the atom by strong forces of attraction operating between the negative electrons and the positively charged nucleus. It is quite possible to imagine the electrons revolving in orbits about the nucleus much as the planets in our solar system revolve about the sun.

Although the question as to the size of subatomic particles has very little

trical charges! The next time we run into a door in the dark we may find some consolation in remembering that it is really nothing meeting nothing.

FURTHER SUBATOMIC PARTICLES

The nuclei of all atoms other than the hydrogen atom, must contain other subatomic particles than protons. This becomes apparent when we compare the hydrogen and the helium atoms. The helium atom (Fig. 8) is next to the lightest atom, weighing four times as much as the hydrogen atom. If we assign to hydrogen a relative atomic weight of 1 and an atomic number of 1, then helium has an

atomic weight of 4 and an atomic number of 2. The nucleus of a helium atom, therefore, must contain 2 protons about which revolve 2 planetary electrons. However, the helium nucleus weighs four times as much as the hydrogen nucleus since the weight of the planetary electrons is negligible. Yet the helium nucleus contains 2 and the hydrogen nucleus 1 proton respectively! There must be, therefore, neutral particles in the helium nucleus which account for the difference in weight.

These neutral particles were discovered by Chadwick of the Cavendish Laboratory at Cambridge. They are called *neutrons*. A neutron, as its name implies, is uncharged and its weight is approximately equal to that of a proton. They are present in the nuclei of all but the lightest hydrogen atom. Thus the helium nucleus is composed of two protons (equal to the atomic number) and two neutrons (equal to the difference between the atomic weight and the atomic number). From the following general rules the composition of any atom may be readily obtained:

1. The atomic number is equal to the number of planetary electrons and to the protons in the nucleus.
2. The atomic weight minus the atomic number is equal to the number of neutrons in the nucleus.

Thus the uranium atom of atomic number, 92, and atomic weight, 238, is composed of a nucleus of 92 protons and 146 neutrons, about which are 92 planetary electrons.

After we have waded through these rather uninteresting but necessary rules, it is easy to lose sight of their implications. We are, in a sense, re-

constructing the entire universe out of three fundamental particles! How so few particles could have been endowed with such properties that the synthesis of the atoms of the elements from them was inevitable, staggers the imagination. Then, too, these atoms combine to form all matter both inanimate and living. The mystery of life itself and of its evolution on the earth must lie in the nature of these three particles!

THE PLANETARY ELECTRONS

The individual character of the atoms of an element can be readily explained by the arrangement of the planetary electrons in these atoms. This arrangement determines whether the element is a metal or a non-metal; whether it enters into combination with other elements readily, or with difficulty, or not at all; and what the number of atoms of each element will be in the molecule of the compound which they form. This arrangement also determines the colors of the light emitted when the element is excited by electron bombardment in a discharge tube. A knowledge of the planetary electron distribution within the atoms is, therefore, of the utmost importance to both chemists and physicists.

A clue to the acquisition of this knowledge is to be found in the periodic table (Fig. 10). In Group O of the table is found a family of inert gases—so inert that they absolutely refuse to form compounds. Their atoms must be of unique stability. The first of these gases is helium, whose atom contains two planetary electrons. This pair of electrons is thought to be located on the surface of the same imaginary sphere, with the nucleus of the atom at its center. This surface

is called the first shell or, more frequently, the first quantum level. All other atoms, more complex than helium, have two electrons in this quantum level. Because of the extreme stability of the helium atom, two electrons constitute its full quota. The next inert gas is neon, the tenth element in the list, with consequently an atomic number of 10. Its 10 electrons are arranged two in the first level and eight in the second. Again, because of the inertness of neon, eight electrons are the full quota of the second shell. Similarly, all atoms more complex than neon have two

may be pictured as occupying one of the four vertices of an imaginary pyramid, or tetrahedron.

WHY ATOMS COMBINE

The atoms of the elements of the other groups in the periodic table have less than eight electrons in their outermost quantum level. The number in this level is the same as the group number to which the atom belongs. Thus the atoms of each element in Group I have one electron in their outer shells, and it is this resemblance which is responsible for their similar properties. The reason why atoms

		GROUPS									
		I	II	III	IV	V	VI	VII	0		
Valences		+1	+2	+3	+4 -4	+5 -3	+6 -2	+7 -1	0		
PERIODS	1	 Hydrogen								 Helium	
	2	 Lithium	 Beryllium	 Boron	 Carbon	 Nitrogen	 Oxygen	 Fluorine		 Neon	
	3	 Sodium	 Magnesium	 Aluminum	 Silicon	 Phosphorus	 Sulfur	 Chlorine		 Argon	

Fig. 10. Periodic table of the chemical elements. Arrangement in groups is made according to the number of electrons in the outer ring

electrons in their first quantum level and eight in the second. The 18 electrons in the argon atom, the next inert gas of atomic number 18, are placed two in the first, eight in the second and eight in the third level.

The structure of the atoms of the remaining inert gases are more complex, but each has eight electrons in its outermost shell. These eight electrons, which characterize the outermost levels in all inert gas atoms but helium, seem to be grouped in pairs, each of which is at the same distance from the nucleus and from the other three pairs. Each pair of electrons

combine to form molecules of compounds is that they try to attain the stable electron structure of the nearest inert gas atom. Since metallic elements are found in the lower numbered groups of the periodic table and hence have fewer than half the full quota of electrons in their outer shells, their atoms tend to lose the electrons in these shells and so resemble the next lower inert gas. On the other hand, atoms of the non-metals in the higher numbered groups have fewer empty spaces to fill up in order to complete the quota of eight, and hence tend to gain electrons to

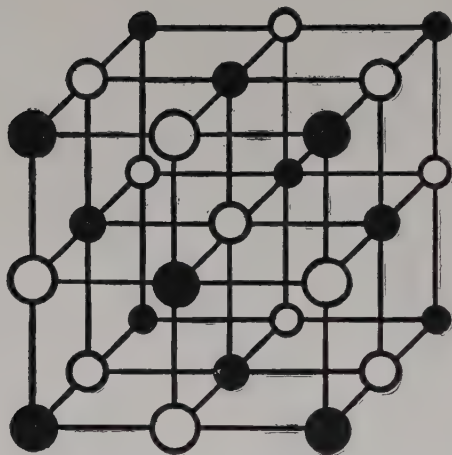


Fig. 11. Cubical arrangement of the sodium chloride crystal

fill these spaces and resemble the next higher inert gas.

ATOMIC COMBINATION

Thus metal atoms tend to combine with non-metal atoms, the former losing electrons to deplete their outer shells and the latter gaining electrons to complete those shells. To illustrate, sodium is an active metal in Group I with an atomic number of 11 and chlorine, a non-metal in Group VII with an atomic number of 17. Their atoms, therefore, have 1 and 7 electrons, respectively, in their outer shells (Fig. 10). When these elements combine, an electron passes from the outer shell of each sodium atom into the empty space in the outer shell of each chlorine atom. Then each atom will have the electron structure of an inert gas. The nucleus of each atom, however, retains its characteristic charge and hence each atom retains its identity. Further each type of atom is no longer electrically neutral. Each sodium atom has now only 10 electrons but its nucleus still con-

tains 11 protons. Hence the atom as a whole has a unit positive charge. The chlorine atom, on the other hand, has gained an additional electron and now has a unit negative charge. Such charged atoms are called *ions* and strong forces of electrical attraction hold the oppositely charged ions together in the crystals of the compound formed. The crystal structure of sodium chloride, or common table-salt, is shown in Fig. 11. In these crystals each ion is surrounded by six equidistant ions of opposite charge in a cubical space-pattern.

If an element of Group II, like calcium combines with chlorine, each calcium atom has two electrons to lose and hence supplies one to each of two chlorine atoms. Therefore, the crystals of calcium chloride contain twice as many ions of chlorine as of calcium.

When such ionic crystals are heated until they melt, the ions are free to move within the liquid and for this reason the liquid is a conductor of electricity. If two carbon rods, or electrodes, connected to the two leads from a source of direct current, are dipped into the liquid (Fig. 12), the positively charged metal ions move to the negative electrode and the negatively charged non-metal ions move to the positive. When a metal ion touches the negative pole, it gains a number of electrons equal to its charge and becomes a neutral atom of the free metal again. On the other hand at the positive pole the non-metal ions lose their extra electrons and become free non-metal atoms. Thus the electric current may be used to decompose melted ionic compounds into their constituent elements. By this method the active metals, aluminum, magnesium, and

sodium, are being prepared for large-scale commercial purposes.

COVALENCE

The ionic type of bond is formed when metals combine with non-metals to form a class of compounds known as salts. Due to the strong force of electrical attraction between the ions of a salt, such substances are invariably solids at ordinary temperature. There remains, however, a second type of bond between atoms of like kind or of elements close to the middle of the periodic table; e.g., in Group IV. It will be recalled that the gaseous elements, hydrogen, chlorine, oxygen, and nitrogen, exist in the form of molecules which contain two atoms of the element. Such molecular atom-pairs have solved the problem of filling up the empty spaces in their outer shells by sharing pairs of electrons. The hydrogen atom with its one electron needs only one more to complete its one electron shell, since two electrons are the quota for the first shell. Thus two hydrogen atoms by sharing their electrons are able to fill their one and only shell. Each chlorine atom has seven electrons in its outer shell and hence one space to fill. By sharing an electron-pair this space is filled in each atom:



Oxygen atoms have six outer electrons with two spaces to fill and hence share two pairs of electrons:



By this rather ingenious mode of union each atom remains electrically neutral and forms self-satisfied molecules. Now the force of attraction

between such neutral molecules is relatively feeble, especially if the weight of the molecule is small. Hence substances composed of molecules in which the atoms are linked by electron pairs are usually gases under ordinary conditions. As the molecular complexity becomes greater, however, these substances may be liquids or even solids at ordinary temperature. However, in the liquid state, unlike the melted salts, they do not conduct an electric current through a media of their own composition.

The element carbon at the top of Group IV invariably is linked by electron-pair bonds in the molecules of the compounds which it forms. Since organic compounds always contain carbon, the electron-pair type of

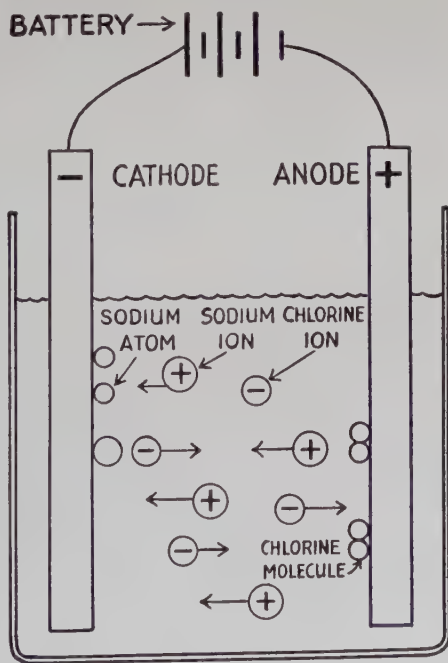


Fig. 12. The separation of sodium and chlorine ions when an electric current is passed through a salt solution

linkage is very important in organic chemistry, as we shall see somewhat later in our study.

ISOTOPES

The discovery of heavy hydrogen by H. C. Urey of Columbia University, in 1931, and the interesting properties of the heavy water which it forms with oxygen aroused popular interest in the existence of isotopes. These are atoms of the same element with different atomic weights. In terms of atomic structure, the different isotopic atoms of the same ele-

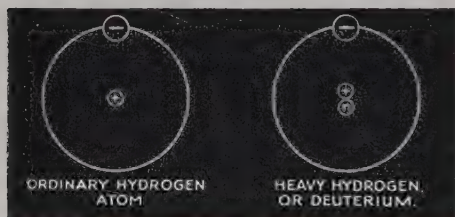


Fig. 13. Comparison of the ordinary and heavy hydrogen atom showing the additional neutron in the heavy hydrogen nucleus

ment have the same nuclear charge and planetary electron system but different numbers of neutrons in the nucleus. That elements may be composed of isotopes was discovered by Sir J. J. Thomson as early as 1912, when he succeeded in separating the isotopes of neon. One of the isotopes has an atomic weight of 20, and the other a weight of 22. In the succeeding years over 400 isotopes of the elements have been discovered. Indeed very few elements are composed of only one kind of atom. Since isotopes of a given element have the same planetary electron system, their properties other than their weight are practically identical. Hence their separation is by no means easy. The

difference between ordinary hydrogen atoms and those of heavy hydrogen can be readily seen in Fig. 13. The nucleus of ordinary hydrogen is a single proton whereas that of heavy hydrogen consists of a proton and a neutron. There are about 5,000 ordinary hydrogen atoms to 1 of heavy hydrogen in nature. Heavy hydrogen is frequently called deuterium and its nucleus, the deuteron. The molecules of heavy water contain two deuterium and one oxygen atom.

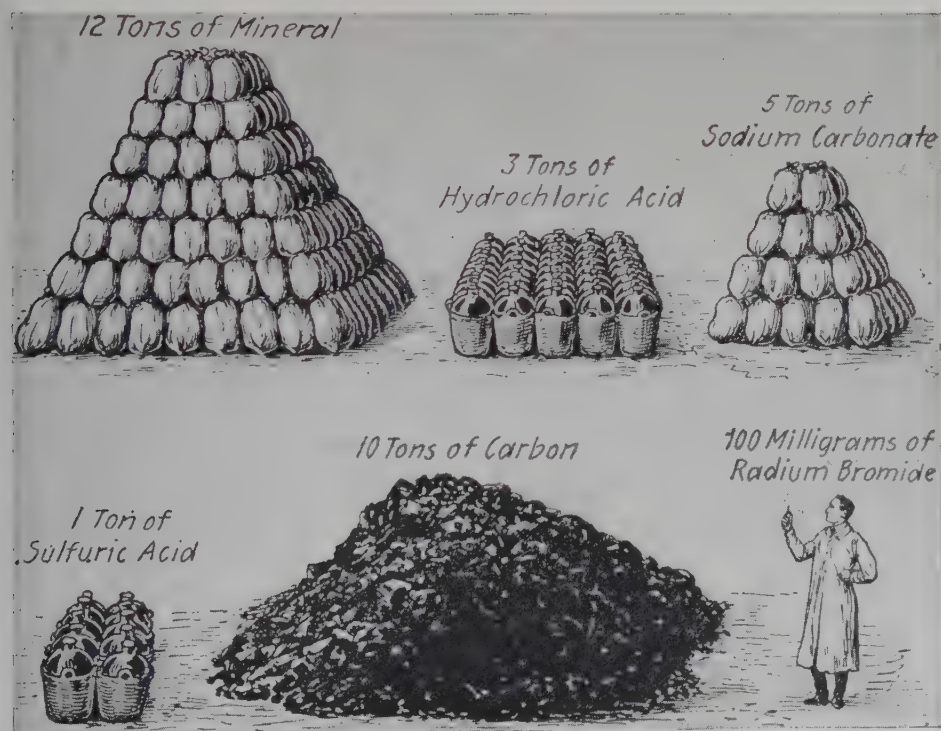
RADIOACTIVITY

The last decade of the nineteenth century was noteworthy for the startling discoveries of X-rays, radioactivity, and of the subatomic particles. X-rays were discovered by Roentgen, in 1895, while investigating the beautiful green fluorescence of the glass walls of an electron discharge tube. They possess the astonishing ability to penetrate the black, lightproof paper in which photographic films are wrapped, and to expose such films. The nature of X-rays will be discussed later but their discovery suggested to Becquerel the investigation of certain substances which were naturally fluorescent to find out whether X-rays were associated with fluorescence in general. His experiments were simple. A fluorescent substance was placed upon the dark paper wrapping of an unexposed photographic plate to test whether radiation similar to X-rays was emitted. Of all the fluorescent substances tested, only compounds of the elements thorium and uranium exposed such protected photographic plates. This marks the discovery of radioactivity. The rays emitted by radioactive elements may be readily detected by their property of making the air surrounding them a

conductor of electricity. By the use of an instrument called the electro-scope, the conductivity of the air surrounding the radioactive material can be determined and the radioactivity of the material estimated.

The names of Pierre and Marie Curie are known the world over, but their great contributions are only vaguely understood by the layman. In the year 1897 Mme. Curie and her husband began their study of radioactivity. They were able to prove that the activity of uranium compounds remains constant over long periods of time; that it is exhibited by

all uranium compounds; and that the activity of pure uranium compounds is proportional to the amount of uranium and in no way to the elements with which it is combined. The conclusion was obvious that the radioactivity is a property of uranium atoms and not of the other atoms in the molecules of uranium compounds. Since thorium and uranium, the heaviest of the then known atoms, were the only ones to show activity, it seemed quite plausible to suppose that their activity was in some way connected with the complexity of their component atoms.



American Society for the Prevention of Cancer

Fig. 14. This drawing makes it clear why radium is so expensive. From 12 tons of pitchblende and 19 tons of chemicals comes one-tenth of a gram of radium. Pitchblende comes usually from the Belgian Congo and from Canada, though it is found in smaller quantities in Austria, the United States and several other countries throughout the world. In medical practice, radium is now commonly used in the treatment of cancer.

DISCOVERY OF RADIUM

When the activity of natural ores and minerals containing uranium and thorium was determined, a surprising discovery was made. The activity of these minerals was far greater than could be expected from the thorium or the uranium in them. This was a direct indication of the presence of one or more hitherto undiscovered elements of far greater activity than thorium and uranium. The laborious search for these elements began, starting with a ton of pitchblende ore from which the uranium had been extracted. In 1898 the discovery of two new elements, polonium and radium, was announced. From a ton of the ore the Curies obtained 0.1 gram of pure radium chloride.

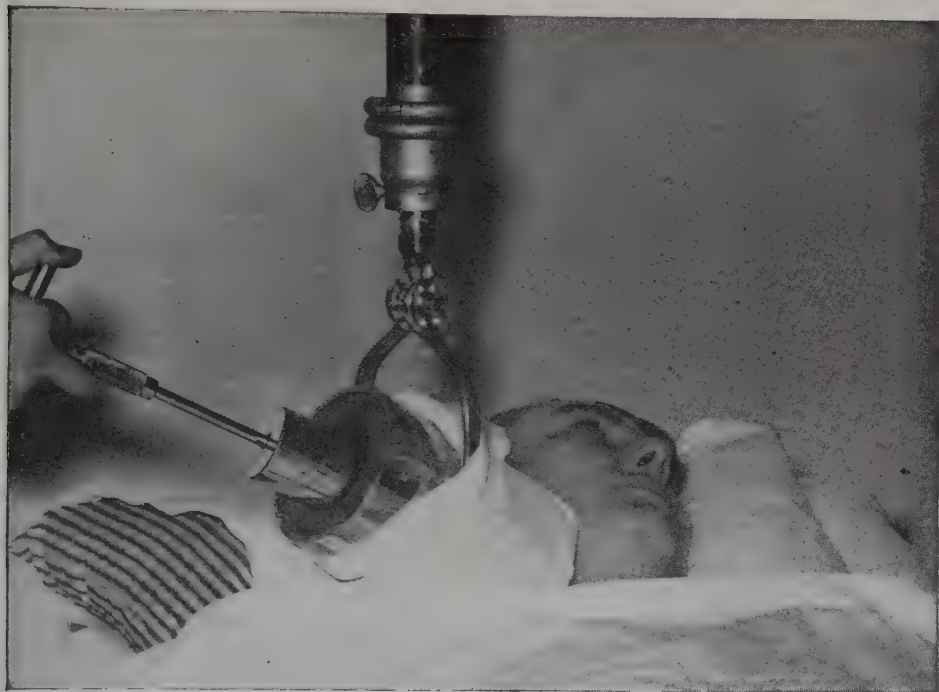
The discovery of radium revealed phenomena which were unique in the history of science. Its tremendous radioactivity, some 3,000,000 times that of uranium, aroused public interest. Here was an element whose atomic weight placed it below barium at the bottom of Group II of the periodic table and whose chemical behavior entirely justified this classification. Yet atoms of this element, unlike those of barium or of any other non-radioactive element, emit material subatomic particles with high velocities approaching that of light, and emit rays similar to X-rays but of far greater penetrating power. Furthermore, the rate at which these particles are emitted depends only on the number of radium atoms present, and, unlike other changes, this rate remains the same no matter how high the temperature or the pressure. What was the source of this energy? A given amount of radium produces enough energy in an hour to raise

one and one-half times its own weight of water to the boiling point. The suspicion grew that tremendous stores of energy were in some way lying dormant within the atoms of the elements, and that the most complex atomic nuclei, through their instability and resultant radioactivity, gave evidence of the existence of this power.

NATURE OF RADIOACTIVITY

The late Lord Rutherford should be given the major credit for the explanation of the nature of radioactivity. He found that two types of particles are emitted. The so-called alpha particles are nuclei of helium atoms and, therefore, consist of two protons and two neutrons. The second type, beta particles, are electrons. The gamma rays proved to be invisible light rays, similar to X-rays but of shorter wave length and hence of greater penetrating power. The material particles are emitted from the nuclei of the radioactive atoms at speeds approaching that of light.

The nucleus of a radium atom is made up of 88 protons and 138 neutrons, since its atomic number is 88 and its atomic weight 226. This atom characteristically emits an alpha particle. By subtracting the 2 protons and 2 neutrons of the emitted alpha particle from the radium nucleus, we find that what is left is a nucleus of 86 protons and 136 neutrons. This would no longer be a radium atom nucleus but one of an element of atomic number 86 and of atomic weight 222. The element of atomic number 86 in the periodic table is radon, one of the inert gases of Group 0. This leads to the startling conclusion that when radioactive disintegration takes place new atoms of different elements are formed! This



U.S. Public Health Service by Lee

Fig. 15. Radon, a heavy gas formed in the disintegration of radium, is used in the treatment of cancer. Here the "pop gun" containing the radon goes into the container just before treatment begins

conception was revolutionary, for chemists had always considered the atoms of the elements as indestructible particles which could not be changed into atoms of other elements. Such a transmutation was almost unthinkable, for the failure of the alchemists to change baser metals into gold had been explained by the impossibility of transmuting one element into another. But Rutherford's evidence could be explained by no other hypothesis. The disintegration of radioactive elements, however, was entirely out of scientists' control, since it proceeded at a rate which could not be changed.

The use of radium in the treatment of cancer (Fig. 15) has created a de-

mand for this rare element. It occurs in all minerals which contain the element uranium, as this element is the parent of a family of radioactive elements which includes radium. In other words, radium is formed by the disintegration of atoms of higher atomic weight which, in turn, are disintegration products of uranium. There are only about $1/3,000,000$ as many radium as uranium atoms in a natural ore. The cost of extracting the radium is high, so that it sells for about \$25,000 a gram (Fig. 14).

TRANSMUTATION

A knowledge of atomic structure makes the problem of changing an atom of one element into that of an-

other very simple—at least on paper! One has only to change the charge on the atom nucleus and it becomes an atom of another element. If three protons could be removed from the lead atom-nucleus (atomic number 82), a gold atom (79) would result. If this could be done on a large scale at low cost, gold would be so plentiful as to be valueless as a monetary standard. Actually the problem is much more difficult. The nucleus of an atom is an extremely tiny particle and is usually well protected by the sheath of planetary electrons. In addition, the energy required to change the nucleus of an atom is of the order of a million electron volts! If the nucleus of an atom could be hit by a subatomic particle moving so swiftly that its kinetic energy were of this order of magnitude, then transmutation might take place. Reasoning in some such fashion, Rutherford realized that he had a source of such high-speed particles in the alpha particles emitted by radioactive atoms. By letting millions of such particles bombard the atoms of an element, at least some might score direct hits on nuclei of the target atoms and transmutation might result. In 1919 he was able to report the first successful transmutation. Bombarding the atoms of nitrogen gas with alpha particles, he succeeded in knocking protons loose from the nuclei of a relatively few nitrogen atoms. These became atoms of carbon.

"Atom-smashing," as the newspapers call it, is now one of the most interesting fields of research in physics. Giant machines have been designed and erected in which protons or deuterons are given the necessary energy of motion and then allowed to crash into a target of the element to

be transmuted. The cyclotron is a machine of this type designed by E. O. Lawrence of the University of California. Between the poles of a gigantic electromagnet charged subatomic particles, i.e., protons, move in circular paths. Their speed is increased regularly, after they have moved around half a circle, by an alternating electrical field. The faster they move, the greater the radius of their circular path. Finally, when each has acquired sufficient energy, it is directed against the target atoms and transmutation results. Protons may be given as much as 30,000,000 electron volts of energy in such a machine. A ray of countless millions of such particles emerging from a cyclotron possesses an impressive amount of energy. However, only a small fraction of the protons actually hit atom-nuclei and cause transmutation.

In 1934 the Curie-Joliot's made a spectacular announcement. The daughter of Mme. Curie and her husband discovered that the products of certain transmutations are radioactive! For example, when aluminum is bombarded by alpha particles, a radioactive form of the element phosphorus is formed. These radioactive atoms are isotopes of phosphorus which do not occur in nature. Soon many other radioactive atoms were reported by Fermi of the University of Rome. The discovery, by Lawrence, of a radioactive type of sodium atom among the products, when salt was bombarded with deuterons, was given much publicity by the newspapers all over the country. These atoms emit beta particles and gamma rays. Their therapeutic value in the treatment of cancer and other previously-thought incurable diseases is now being tested.

SUBATOMIC ENERGY

As a deduction from his theory of relativity, Einstein was able to calculate the amount of energy which would be created if a given amount of matter could be destroyed. The calculation is simple. One has merely to multiply the mass of the matter destroyed in grams by the velocity of light squared to obtain the energy created. Since light moves at the tremendous velocity of 186,000 miles, or 30,000,000,000 centimeters, a second, the square of this velocity is no small number. Thus the destruction of a relatively small mass results in the liberation of large amounts of energy. According to Brasch, a German physicist, if the mass of a ton of coal, or, for that matter, a ton of any material,

were converted into energy, sufficient heat would be generated to melt all the ice in the North Polar Cap! Small wonder that some physicists began to feel uneasy. If a method for converting matter into energy were discovered and applied, the first successful experiment might also be the last. The sudden liberation of energy might detonate all the atoms of the earth and a new star might appear in the heavens where the solid, comfortable Mother Earth once was!

These fears have not been justified by the results. Transmutation reactions are accompanied by a loss in mass; that is, the product atoms weigh less than the atoms which enter into the transmutation. The loss in mass appears as the kinetic energy of the



Life Magazine

Fig. 16. Professor E. O. Lawrence (left, crouches by the cyclotron of which he is the inventor. With him is his research associate, Dr. F. N. W. Kurie, who aided him in designing the machine

product atoms. For example, when a lithium atom is hit by a proton, two helium atoms are formed which weigh only 0.000,000,000,000,000,000,000,333 grams less than the atoms from which they were formed. However, the destruction of this almost infinitesimal mass results in the liberation of over 17,000,000 electron volts of energy! Great though this amount of energy may be on an atomic scale, it is only a small fraction of the energy required to operate a cyclotron, so inefficient are our methods of trans-

mutation. When radioactive atoms disintegrate the source of energy is the accompanying mass destruction. The energy radiated into space by the sun and by the other stars is probably generated by the destruction of matter. However, such is the vastness of their masses that the constant drain on their resources has little effect. The sun, for example, may be parting with 360,000,000,000 tons of matter daily, but there remains sufficient matter to last for 15,000,000,000,000 years.

CHAPTER 12

HEAT

THE history of the struggle which man has fought to obtain mastery over his environment is marked by his increasing ability to put to his uses the materials which nature furnishes. Primitive man fashioned his implements of stone, and still later of an alloy of the metals tin and copper, which is called bronze. Only comparatively recently has the method by which iron may be extracted from its ores been discovered. More slowly came the appreciation and utilization of energy. The use of the winds to drive ships came early, but the harnessing of the energy of fire to drive machines was accomplished only a few centuries ago. Indeed a clear idea of the existence of energy is less than a century old. Yet man is dependent for his very existence on the radiant energy, which comes to the earth through the vacuum which separates this planet from its source, the sun.

Material things are readily comprehended. They make a direct impression on our senses. The quantity of matter in them can be weighed. Furthermore, the changes which matter undergoes are accompanied by no loss in weight. In short, the quantity of matter remains constant. Energy on the other hand is an illusive will-o'-the-wisp; now giving evidence of its existence and then mysteriously seeming to disappear. Energy can be defined in a rather general way as an ability to do work; material particles when they are in motion possess kinetic energy. Naturally, the heavier the body and the greater its speed, the greater is its kinetic energy. In

fact, this energy is equal to one-half the product of its mass by its velocity squared. If, for example, an automobile doubles its speed, it possesses four (2^2) times as much energy. So if its driver feels he must collide with a telephone pole, the damage will be only one-fourth as great if he can halve his speed before collision occurs.

We have mentioned the fact that at times kinetic energy seems to vanish, and yet the total energy in any closed system remains constant. When this occurs, kinetic energy is stored as potential energy. When a storage battery is being charged, the energy of the moving electrons of the electric current is being stored as a form of potential energy within the materials of which its poles and the solution between them are composed. When later the battery is called upon to start a car, this stored energy springs to life again as the kinetic energy to turn over the motor of a powerful engine. No one need be reminded of the energy generated by the combustion of coal and of petroleum products which makes the wheels of our machine age turn. Yet, to a savage who has never seen coal burn or a motor car moving at high speed, the presence of this potential energy would never be suspected.

KINETIC ENERGY

For convenience, physicists use a classification of the different kinds of kinetic energy which is based on the size of the body in motion. A moving state of matter, such as a gas, a liquid,

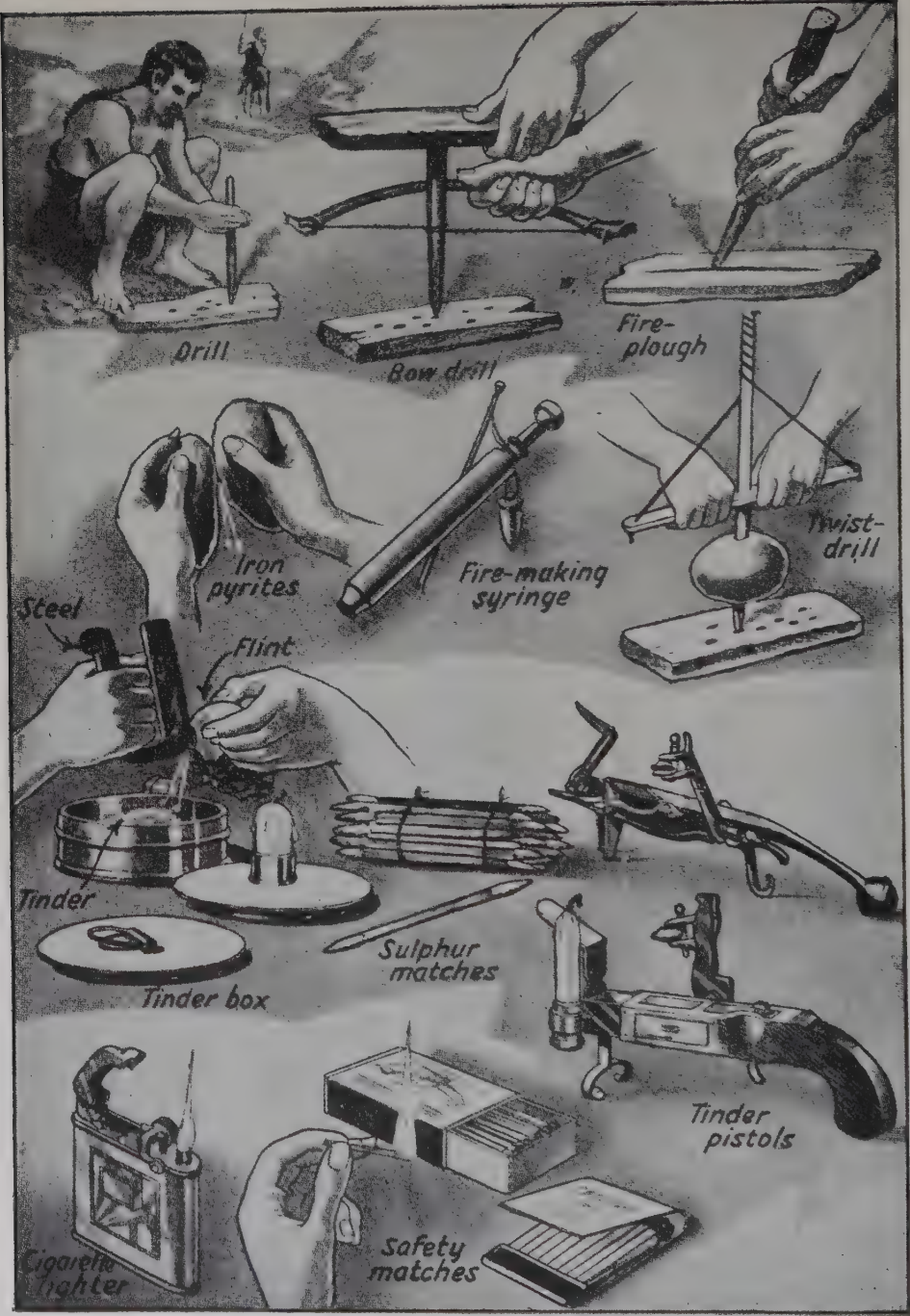


Fig. 1. Examples of primitive and modern methods of fire making

or a solid, possesses mechanical energy. The energy of the wind, of the waterfall, or of an engine, is of this type. The energy of moving molecules or atoms is that of heat. Finally that of the moving stream of electrons in a current of electricity is electrical energy.

Energy is stored as potential energy whenever work is done against a force of attraction or repulsion. Everyone, even the smallest child, is conscious of the force of gravity. Yet the explanation of this mysterious action which takes place across the distance between any two masses in space, is as fragmentary today as it was at the time of Newton. All we can say is that there exists a tendency for any two masses in space to move together as if they were impelled by a force which varies inversely as the square of the distance between them; if the distance is halved the force is quadrupled. But no one has ever succeeded in discovering what it is that exerts this force.

We should be quite wrong in assuming that the Newtonian apple was attracted to the earth, or, in the eyes of the worm in the apple, that the earth was attracted to the apple. These are inanimate things which have no personalities and hence cannot attract each other. However, the existence of such a force makes it possible to store energy. When grandfather wound up his clock he did work against the force of gravity in raising the weights. The energy which he used was stored in these weights. Once the weights were allowed to fall slowly, this potential energy reappeared again as the kinetic energy of the running clock. A ball thrown into the air is moving against the force of gravity and its initial kinetic energy

is converted into potential energy as it rises. At the top of its flight its energy is entirely potential. When it falls the reverse process takes place as potential energy once again reappears as kinetic.

There are two other types of action at a distance: electrical and magnetic attraction or repulsion. If objects bear an unlike charge of electricity, that is, if one is positively and the other negatively charged, they tend to move together as if impelled by a force of attraction. However, if both bear a charge of the same sign they tend to move apart as if they repelled each other. The ends of a magnetized bar of iron are its poles. If the bar be mounted on an axis so that it is free to swing freely about its center of gravity, one pole will tend to point to the north magnetic pole of the earth and the other to the south. This phenomenon is familiar in the compass needle. Opposite poles of two magnets, one north and one south, attract each other and like poles repel. Here again, such action at a distance may be used to store potential energy.

The atoms of the elements, as we have seen, are made up of negatively charged electrons and positively charged protons. Within these atoms electrical forces are at play which make possible the storage of energy. Furthermore, as we shall see, a moving electric charge creates a magnetic field of influence in the space surrounding it. Hence magnetic forces are present. These electrical and magnetic forces permit the storage of energy in the form of coal (Fig. 2), petroleum, and matter in general. Matter may then possess energy in two different forms: as kinetic energy, due to its motion, and stored as potential energy.

No sample of matter is ever without energy but energy can exist without being associated with matter. Such "disembodied" energy is called radiant energy, or light. In this form it travels through space with a constant and incredibly high velocity of 186,000 miles a second. In a sense, light is pure energy.

THE UNIQUE NATURE OF HEAT

The great Sir Isaac Newton, in 1686, stated his three fundamental laws of motion. The first of these states that every sample of matter will remain at rest or will move with constant velocity in a straight line unless acted on by some force. If we were to imagine a moving body so far out

in space from any other mass that no gravitational force is acting on it, then this body would move in a straight line at constant speed forever. Under such conditions perpetual motion, far from being impossible, would be the rule.

However, on this earth the results are quite different. A moving body soon comes to rest with its kinetic energy converted into heat energy. A railroad train cannot move long after its coal is gone nor an automobile after its gas tank is empty. Sooner or later the energy of large bodies of matter in motion is changed by the process of friction into heat. Our modern roller bearings are far more efficient than the crude bearings in



Baltimore & Ohio Railroad

Fig. 2. Coal is a widely used and well-known source of energy. Fed by the stoker into the boiler of a modern locomotive, it supplies the power for most of our railway transportation. Very few countries have a richer supply of this form of natural energy than the United States

earlier machines, but they are not perfectly frictionless. Heat, the ultimate fate of all other forms of energy, is unique for this reason, and a study of its fundamental nature is of tremendous importance to a machine-run civilization.

As we have said, heat energy is primarily due to the energy of molecular motion. Indeed, the kinetic energy of the constituent molecules of a substance is the factor which determines the temperature of the substance. Now this molecular motion is entirely random; that is, the countless molecules of a particle of visible size are moving in an absolutely unordered fashion. Under these circumstances the same number will normally be moving in every direction. This must be the case with gases, for they exert the same pressure, due to molecular bombardment, on every surface bathed by the gas. This could only be the case if the same number of molecules is hitting every square inch of surface in contact with the gas. When the energy of a moving body is converted into heat, that is, when friction develops, the ordered motion of the body as a whole is scrambled up among its molecules. Ordered motion becomes random. Since the molecular kinetic energy has been increased, the temperature of the body is raised.

Now to run a machine requires ordered motion; thus every bit of ordered motion scrambled into heat by friction is just that much wasted energy which cannot help run the machine. Every jar and every rubbing of surface across surface represents a waste of energy. If a perfectly frictionless machine could be invented, it would remain in perpetual motion when once started. The perfectly fric-

tionless bearing may be imagined *but* it is highly improbable that it will ever be invented. Don't invest money in a perpetual-motion machine!

The only type of perpetual motion possible on this earth is the motion of the molecules. Since the energy of their motion *is* heat, none can be lost when they collide with one another. In other words no friction can develop. Molecules are, therefore, perfectly elastic. That this must be the case is indicated by the following fact. The best evidence we have of molecular motion is the pressure which gases exert, since this is the direct result of the bombardment of their molecules on the walls of the container. If a definite weight of a gas is confined at a constant temperature in a given vessel, the pressure will remain forever the same. This could be the case only if the molecules lose none of the energy of motion in their countless collisions with one another. When larger bodies collide, the resulting jar converts a portion of the ordered motion of the bodies as a whole into the random heat motion of their molecules. Hence masses larger than molecules cannot be perfectly elastic.

TEMPERATURE

The temperature of a sample of matter is in a sense a measure of the intensity of the heat energy which it possesses. However, it is in no sense a direct measure of the amount of heat. This paradox may be understood if we compare the amount of heat energy in a ton and in a pound of iron at the same temperature. Obviously the ton of iron requires far more heat to be heated to the same temperature than does a pound of the same material. If two bodies at the same tem-

perature are brought into contact, no flow of heat is apparent and both remain at the same temperature. But if there is a difference in temperature, heat will flow from the hotter to the colder body until the temperature of each is the same.

The mechanism by which heat energy is conducted from the hotter to the colder body is easily explained in terms of the picture of heat as the kinetic energy of molecules. The temperature of a body is determined by the kinetic energy of its molecules. The molecules in bodies at the same temperature have the same kinetic energy. If there is a temperature difference, however, the molecules of the hotter body are moving with the greater kinetic energy. In the latter case, at the surface of contact the collisions between molecules will result in those of the colder body gaining the kinetic energy which is lost by those of the hotter body. Anyone who is familiar with the game of billiards will remember that when a collision occurs between a faster and a more slowly moving ball, the former moves more slowly and the latter more rapidly than it did before collision. The result is that the colder body grows warmer and the hotter body colder, until their temperatures are the same.

The appreciation of temperature, like astronomical mileage, is a matter of fixing a datum line according to our experience and surroundings. To us in the temperate zones, 80° F. in the shade is "hot" but to those who live in India it is "cool." The planet Mercury's temperature of 675° F. would be more than fatal to us, but it is nothing compared to the sun's surface heat of $10,000^{\circ}$. And even this extraordinary temperature would be "cool" compared with the $120,000^{\circ}$ of

the stars on the edge of the planetary nebulae, with a probable $1,000,000^{\circ}$ at their center—figures which, of course, mean next to nothing to us, for they are quite beyond the ability of our mind to conceive.

Our personal sensations of temperature are often misleading, our impressions being governed moment by moment by the state of our body. Sitting in a room we may feel that it is cold, yet someone coming into it after a sharp walk or some vigorous exercise may complain of the heat of the room. You may conduct an interesting experiment by taking three bowls of water, one cold, one lukewarm, and the third hot. If you hold one hand in the cold water and the other in the hot water for a few moments, and then plunge both hands into the lukewarm water, the hand that has been in the cold water will feel the lukewarm water hot, while the hand in the hot water will feel it cold.

Then again, the conductive powers of different bodies mislead us. On a cold morning a poker feels cold, but a wooden chair feels comparatively warm; yet the thermometer would show that both poker and chair are at the same temperature. We are thus led to the conclusion that heat is a factor to which our senses are an unreliable guide.

HOW TEMPERATURE IS MEASURED

Temperature is measured by a thermometer (Greek: *thermos*, "heat," and *metron*, "measure"). The instrument, of course, is misnamed "heat measurer," for, as we have seen, it does not measure heat but temperature. Most thermometers depend for their working on the fact that a body expands when heated and contracts when cooled.



Bausch and Lomb Optical Company

Fig. 3. An optical pyrometer can be focused on an object to determine its temperature. This is possible because the relationship between heat intensity and light intensity is fixed and known

However, many other properties of matter vary with the temperature. Therefore any of the properties which depend upon the temperature may be used for its measurement. We may roughly estimate the temperature of a very hot body by its color. A substance becomes red before it grows white hot. Optical pyrometers are used to determine the temperatures of very hot substances by making use of this property (Fig. 3). The difference in electrical potential which exists at the junction of two metals also varies with the temperature, and temperatures are determined with the highest precision by such electrical measurements.

The commonest type of thermometer consists of a glass tube of a very

fine and uniform bore, closed at one end and with a cylindrical bulb at the other, containing a quantity of mercury. Before the mercury is introduced into the tube all air is expelled, the tube being then hermetically sealed and graduated with a scale. When the thermometer is brought into contact with a hot body, the mercury expands and rises in the tube; or, if it is cooled, the mercury in the tube contracts and falls. The temperature of the thermometer's surroundings is thus indicated by the position of the top of the column of mercury in relation to the graduated scale.

The thermometer appears to have been invented by Galileo—certainly he was one of the earliest to use ther-

mometers, in 1592. His instrument (Fig. 4a) consisted of an inverted flask, the long narrow neck of which was immersed in a vessel containing colored water. Some of the air was exhausted from the body of the flask, so that when the neck was inverted in the liquid it rose for a short distance. A graduated scale placed behind the neck indicated the level of the liquid, which rose or fell as the change in the temperature caused the air in the flask to contract or expand.

This type of instrument was modified about the beginning of the seventeenth century. The flask was no

longer inverted and the vessel of liquid became unnecessary (Fig. 4b). A small column of liquid was held in the neck of the flask by capillary attraction. The expansion and contraction of the air in the bulb, caused by change in temperature, made the liquid rise or fall, allowing a rough measure of the amount of change required. There were defects in this type of instrument, however, and an improvement was made by abandoning the use of air, the later instruments having a bulb and tube almost entirely filled with water, the top of the tube being left open (Fig. 4c).

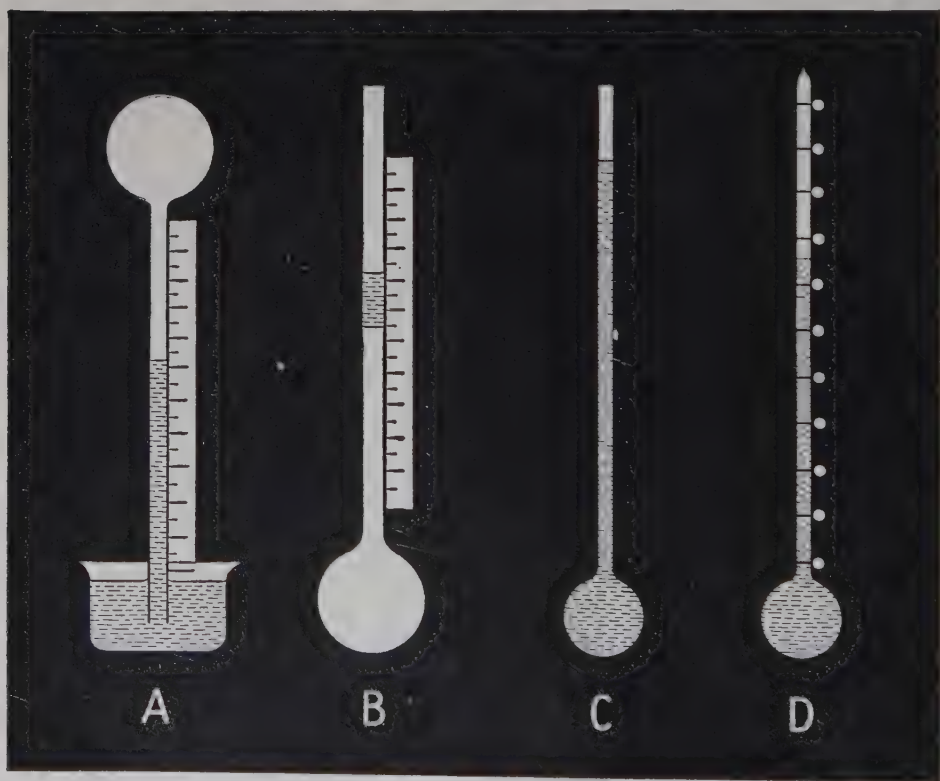


Fig. 4. (A) Earliest type of thermometer, an inverted flask in an open beaker of water. (B) The later open-tube air and water thermometer equally unsatisfactory. (C) Open-tube water thermometer. (D) First closed-tube thermometer using alcohol in place of water.

In 1641 alcohol was used instead of water, and at some time before 1654, the closed thermometer was introduced by Ferdinand II, Duke of Tuscany. In this type, the air was expelled by heat and the tube containing the alcohol was sealed at the top (Fig. 4*d*). The tube was graduated by placing the zero mark at the level indicated by the liquid when the instrument was placed in a certain cellar in Florence in winter. In the following summer the instrument was again placed in the same cellar, the reading then being marked "10," and the space between it and zero being divided into equal parts.

This method of calibration was soon found unsatisfactory, for the cellar temperatures, of course, varied in different years. The melting point of ice was then taken as giving a constant zero, and it was adopted as a uniform standard. A further step was made when Amontons found that the boiling point of water was also constant, and that, too, was adopted as standard.

FAHRENHEIT'S THERMOMETER

In 1714, G. D. Fahrenheit, an instrument maker of Amsterdam, introduced the use of mercury in thermometers and revised the scale used in calibration. For his scale Fahrenheit chose as zero the temperature of a mixture of ice and salt, which is colder than pure ice; and for the higher fixed point he chose the temperature of his body, calling it 96° , which is a conveniently divisible number. This gave him freezing and boiling points of water as 32° and 212° respectively, separated by 180 divisions of the scale.

Six years after Fahrenheit's death, in 1736, the centigrade scale was in-

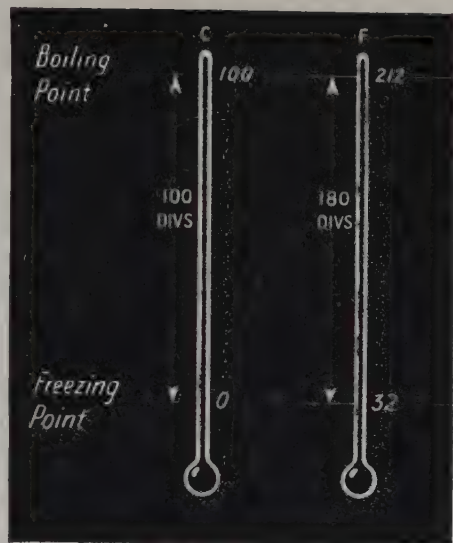


Fig. 5. Centigrade (left) and Fahrenheit (right) thermometers

troduced by Anders Celsius, a Swedish astronomer. As its name indicates (Latin: *centum*, "a hundred;" *gradus*, "steps"), the centigrade thermometer is graded to 100° . In calibrating a centigrade thermometer the bulb is immersed in a mixture of ice and water and the position to which the mercury sinks is marked "0" or zero. The bulb is then placed in a jet of steam from boiling water and the point to which the mercury rises is marked 100, the intervening space between 0 and 100 being divided into equal parts.

FAHRENHEIT AND CENTIGRADE

Both Fahrenheit and centigrade scales are in general use; when stating a temperature it is customary to indicate which scale is used by writing F. or C. after the figure, for a degree in the former represents a lesser difference of temperature than a degree on the latter (Fig. 5). It is useful



Fig. 6. One form of self-registering device in minimum (top) and maximum (bottom) thermometers. Note the concave meniscus at B and convex meniscus at A. See text for explanation of use

to know that we can convert centigrade to Fahrenheit by multiplying the reading by 9, dividing the result by 5, and adding 32. On the other hand, to convert Fahrenheit to centigrade we subtract 32 from the reading, multiply by 5, and divide by 9. Thus:

(1)

$$50^{\circ}\text{C.} \times 9 = 450 \div 5 = 90 + 32 = 122^{\circ}\text{F.}$$

(2)

$$122^{\circ}\text{F.} - 32 = 90 \times 5 = 450 \div 9 = 50^{\circ}\text{C.}$$

The best substance to use in a thermometer is one that expands to the greatest degree for any given rise in temperature. The most convenient substance for everyday use is mercury, for it is regular in its expansion and remains liquid at ordinary low temperatures, its freezing point being -39.1°F. Mercury thermometers are in general use to measure temperatures from about -40°C. to 330°C. Alcohol thermometers are sometimes

used, the liquid being colored black or red. This type of thermometer is sometimes preferred because of the greater visibility of the column of spirit as compared with a column of mercury.

Where it is desired to measure very low temperatures, alcohol or toluol are used instead of mercury. As the expansion of gases is considerably greater than that of liquids, gas can be used to indicate temperatures. Gas thermometers, however, are only used for certain scientific measurements.

Self-registering thermometers are those that record the maximum and minimum temperature readings during the day or night, as may be required. They do this by an ingenious arrangement. In some types of maximum thermometers a small shaped piece of steel is introduced into the tube above the mercury. In some cases it has a spring that presses against the inside of the tube and so retains the index in position (Fig. 6). Thus, on a rise in temperature, the index is pushed up the tube. When the temperature falls it remains behind, and thus indicates the maximum height to which the mercury has risen.

The minimum thermometer uses alcohol and here again a steel index is used (Fig. 6a). The liquid has a curved meniscus and surface tension drags the index back with the liquid when the temperature is lowered. When the temperature rises, the in-

dex is left behind, so recording the lowest temperature reached during the required period. In both cases the indexes are usually reset by being drawn along the tube with a magnet.

A common type of combined maximum and minimum thermometer is shown in Fig. 7. The left-hand round bulb is the thermometer bulb proper, and contains alcohol. The darker substance in the bend of the tube is mercury, and the temperature is indicated on each of the two scales by the ends of this mercury column. The two index pieces can be clearly seen, and it is obvious that the left-hand index will mark the minimum temperature and the right-hand index the maximum in the way already described for simple maximum and minimum thermometers. There is a vacuum inside the right-hand pointed bulb on the maximum side.

ABSOLUTE TEMPERATURE

The best direct evidence we have of molecular motion is the pressure exerted by a gas. This pressure, when the gas is confined in a constant volume, is determined solely by the temperature. The relationship is not a simple one, although it is easy to understand why the pressure rises as the temperature is raised and vice versa. Fortunately all gases behave in the same way. If the temperature of a given weight of gas in a container of

constant volume is lowered from 0° to -1°C. , the pressure is reduced by $1/273$. If it were lowered from 0° to -10°C. , the reduction in pressure would be $10/273$. For example, if the gas sample exerts a pressure of 546 pounds per square inch at 0°C. , its pressure would be reduced by just 20 pounds ($546 \times 10/273$) at -10°C. Its pressure at this lower temperature would be 526 pounds ($546 - 20$). At -273°C. its pressure would be zero since it would have been reduced $273/273$, or its entire amount! In other words, at -273°C. all gases cease to exert pressure. This can only be interpreted to mean that at this low temperature all molecular motion ceases. Since molecular motion determines temperature, when this ceases the absolute zero temperature is reached.

It is possible to define an absolute temperature scale whose zero really means what it says, that is, no temperature. By adding 273° to a centigrade temperature scale the corresponding temperature on the absolute scale can be easily calculated. Thus 0°C. is 273°A and -273°C. is 0°A . The pressure which a gas exerts in a constant volume is directly proportional to its absolute temperature. If the absolute temperature be doubled, the pressure will be doubled. Similarly the volume of a gas kept under

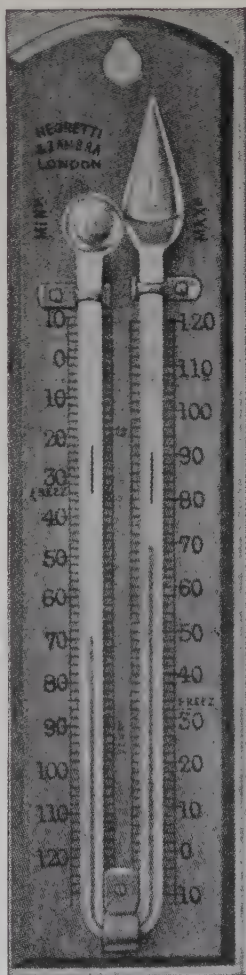


Fig. 7. Self-registering minimum and maximum thermometer

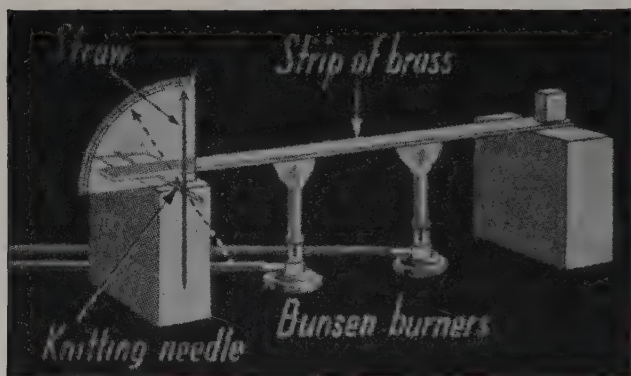


Fig. 8. Experiment proving that solids expand under the influence of heat

a constant pressure is proportional to its absolute temperature.

THE EXPANSION OF SOLIDS AND LIQUIDS

We have just seen that the expansion of gases with an increase in temperature is perfectly regular. With liquids such a regular expansion is not the rule. This is only to be expected, since expansion must take place against the forces of attraction between molecules. Since these are much closer in liquids and solids than in gases, the forces are relatively much greater. Furthermore, these forces vary in strength between molecules of different substances so that we should not expect to find the same degree of expansion for a given temperature rise in different cases.

The molecules in a solid are arranged in space in a regular pattern which is apparent in its crystalline form. Under such conditions free, random, molecular motion could not exist or a solid would

quickly lose its regular shape. The molecules are simply vibrating about fixed points in the crystal structure. The energy of vibration is what determines the temperature of the solid. As the temperature rises, this energy increases and the molecules need more "elbow-room." The result is expansion with fewer molecules per unit volume. The molecules

in a liquid are freer to move, for a liquid has no regular shape. Nevertheless, its molecules are held to a definite volume at a given temperature by intermolecular forces. Here again, when the temperature is raised, the molecular kinetic energy increases and the liquid expands.

The expansion of matter may be easily demonstrated by a few simple experiments. The first experiment demonstrates the expansion of solids. One end of a metal bar is fixed so that it cannot move and the other is supported on a block of wood. Between the wood and the bar is a knitting needle which passes through a straw to act as a pointer, as shown in Fig. 8. If a Bunsen burner or alcohol lamp is placed beneath the metal bar

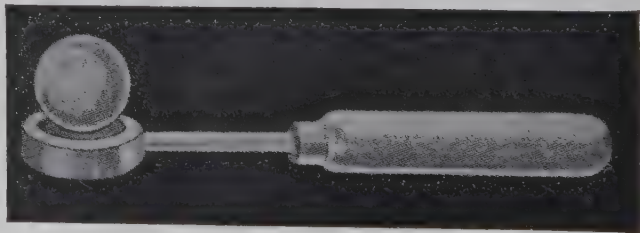


Fig. 9. A metal ball that, when cold, will just pass through a ring, will not do so when heated

it will be found to expand when the heat is applied, the expansion causing the pointer to move as shown in the diagram. Fig. 9 shows another way in which the expansion of solids can be demonstrated.

A second experiment will illustrate the expansion of a liquid when heat is applied. A flask with a tube passing through a cork is filled with water until the level of the liquid reaches the top of the flask. The flask is then placed in a vessel of hot water, and the water in the flask will be seen to rise in the tube (Fig. 10, left). As soon as the source of heat is removed and the flask is allowed to cool, the level of the liquid falls again.

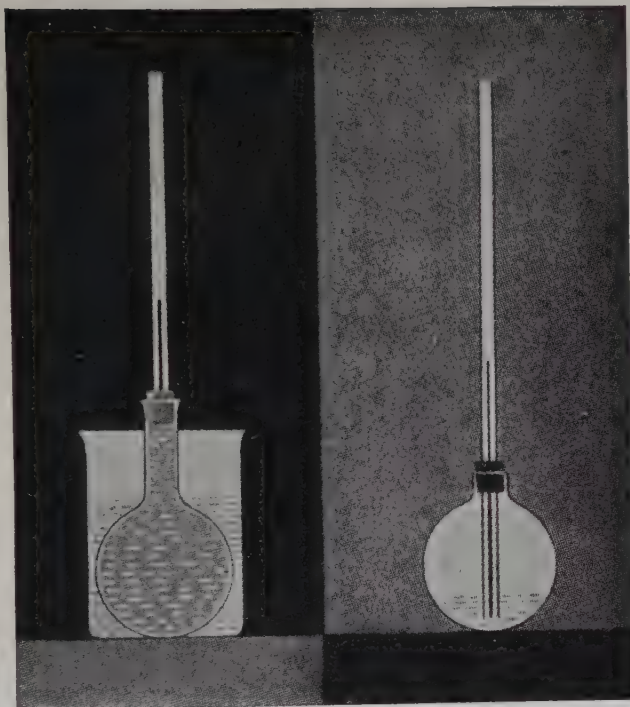


Fig. 10. (Left) Expansion of liquids. The water in a flask placed in a beaker of hot water, rises up the tube. (Right) Expansion of gases. If a flask partly filled with cold water is held in the hand, the heat makes the air inside expand, forcing water up the tube.

The expansion of gases on the application of heat can be shown by partially filling a flask with water and fitting a cork and glass tube in such a way that the bottom of the tube is below the surface of the water. The flask is then held in the hand. The heat causes the air in the flask to expand, thus forcing the water up the tube (Fig. 10, right).

The amount of expansion in length of a substance due to rise in temperature is called the *coefficient of linear expansion*. This is expressed in unit lengths per unit rises of 1°C . Actually, the amount is very small, as will be seen from the following examples:

lead, 0.000029; aluminum, 0.000023; silver, 0.000019; brass, 0.000018; copper, 0.000017; iron and steel, 0.000012 foot. Thus if 1 foot of iron is heated 1°C ., its length will increase 0.000012 foot; if it is heated by 10°C . its length will increase 0.000012×10 , so that it will then be 1.00012 feet long.

MOLECULAR EXPANSION

We have spoken of the increase in the "elbowroom" of molecules that results from the application of heat to a substance. We should make it clear that because the molecules are so minute the actual movement is extremely small. It is because of the

very great number of molecules that the sum of their movement in expanding makes a movement that is perceptible. This movement may be large enough to be detected without measuring instruments. For instance, in long bars of metal the expansion will be apparent even when there is only the comparatively small change in temperature as between a summer day and a frosty day in winter. A 100 foot bar of aluminum will show an increase of $\frac{4}{5}$ inch between freezing point on winter mornings and the 30°C . of a summer noon. Cast iron is affected to a less degree, the difference being $\frac{1}{3}$ inch. A 100 foot glass rod would increase its length by $\frac{1}{4}$ inch.

Although small, these variations are very important, and consequently expansion and contraction have to be allowed for in engineering undertakings. Engineers make allowance for expansion in steam pipes by inserting a curved or U-shaped section. This bends easily and so gives the necessary margin of movement.

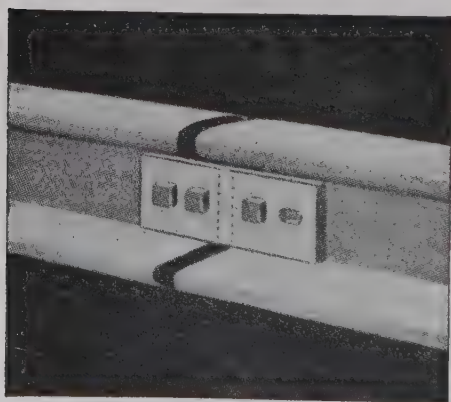


Fig. 11. Expansion in solids. The rails on a railway line have gaps between them joined by fish plates to allow for expansion in hot weather. These are called expansion joints.

For the same reason, railway lines are laid with small spaces, called "expansion joints," between the ends of the rail lengths (Fig. 11), for there may be an expansion of as much as $\frac{1}{4}$ inch in a 60 foot rail. In passing over these spaces the wheels of the train make the "tap-tap" sound, so familiar to travelers. On a cold day, when the rails are contracted and the spaces at their widest, the tapping of the wheels is more noticeable than on a hot summer day when the rails are practically continuous lengths.

On the other hand, streetcar rails are welded together at the joints to form continuous lengths. These rails are sunk in the roadway and surrounded by concrete and granite blocks, so that they are better protected from the changes in temperature to which the unprotected railway rails are exposed. Similarly, we may notice that telegraph wires tightly stretched from post to post in winter appear to "sag" in summer because the rise in temperature causes them to stretch.

EXPANSION OF BRIDGES

The expansion effect is even more noticeable in large bridges. Allowance is made by mounting the girders on rollers to allow them to expand and contract freely (Fig. 12).

Sometimes the girders are fixed to the shore ends by giant hinges, to give the necessary movement, which unallowed for would result in the buckling of the bridge. In suspension bridges the differences of temperature are allowed for by carrying the cables over saddles resting on top of massive towers. These saddles move on rollers that allow of easy movement to accommodate the varying lengths of the suspended span.

On the Brooklyn Bridge the wires of the cables each consist of 19 separate strands, and comprise in all nearly 200 miles of wire to form the span of 1,595 feet. It was essential that each of these wires should be tensioned and secured into place in absolutely uniform weather conditions. The importance of this was realized when it was found that every 1°F . difference in the temperature caused a corresponding deflection of $\frac{1}{3}$ inch in the "sag" of the cables. Consequently, unless the cables had been secured under uniform conditions of temperature, some of them would have been longer than others and the whole of the suspended span would have been thrown out of alignment.

In the case of the Manhattan Bridge, which has a span of 1,470 feet and is suspended by four cables containing 24,000 miles of wire, the saddles do not move on the tops of the towers but are bolted to them. In this case the towers are of steel, whereas those of the Brooklyn Bridge are of masonry to which the saddles could not be so rigidly fixed. Owing to variations in temperature, and to alterations of load, the summits of the towers of the Manhattan Bridge may at times be deflected toward the center of the river by as much as 24 inches.

EXPANSION ON FORTH BRIDGE

There is a difference of as much as 1 foot in the length of the girders of the Forth Bridge, in Scotland, (5,349 feet 6 inches in length) on hot

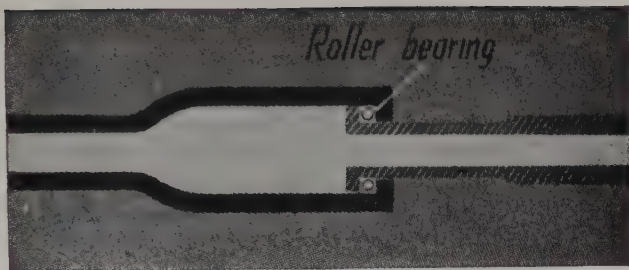


Fig. 12. The sliding joint sometimes used in bridges to allow for the expansion and contraction of the metal parts

and cold days, and this has to be allowed for by using expansion joints. When this bridge was being constructed, the girders were carried out from each cantilever arm so that the river holes on the joint plates were nearly adjacent. In this way they were ready for their final joining-up. The ends were supported on rocking columns to allow for expansion and contraction. A bright day was chosen for joining the two cantilever girders into one continuous girder, when it was hoped that sunshine would cause a sufficient rise in temperature to expand the metal by the necessary amount to enable the girders to be joined. The girders had been carefully set out and were extraordinarily near alignment both horizontally and vertically in the position they were intended to occupy. When the sun rose the bridge responded to the warmth, and the two unconnected girders expanded and gradually moved towards each other. Calculations were upset, however, by the sudden appearance of a cold north-east wind. This caused the expansion of the girders on the eastern side of the bridge to lag behind that of the girders on the western side, with the result that while the bolt holes on the west side came exactly into position

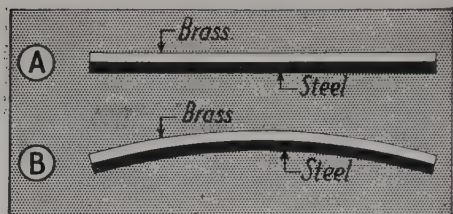


Fig. 13. All solids do not expand at the same rate. Above are compound strips of steel and brass at normal temperature (A). When heated the bar bends towards the steel side (B) because the brass expands to a much greater extent than the steel

those on the east were short by $\frac{3}{4}$ inch—a considerable difference for an engineering job requiring great precision.

The men on the eastern side could not get their bolts into place and for a time the position looked serious, for it was realized that unless both sides

were bolted up simultaneously, great stresses would be caused on the western side, resulting in disaster when night came. Then the Chief Engineer had a bright idea, just as the bolts were about to be withdrawn on the western side. He had quantities of shavings and oily waste collected, soaked in fuel oil, and placed beneath the eastern girder and set afire. Within a few minutes the girder expanded sufficiently to allow the bolts to be driven home.

The expansion of bodies when heated and their contraction on cooling has many useful applications in science and industry. Expansion is used in fixing the metal tires to the wheels of railway coaches. The tire is made slightly smaller than the rim of the wheel, so that when heated it expands and in this state can be fitted

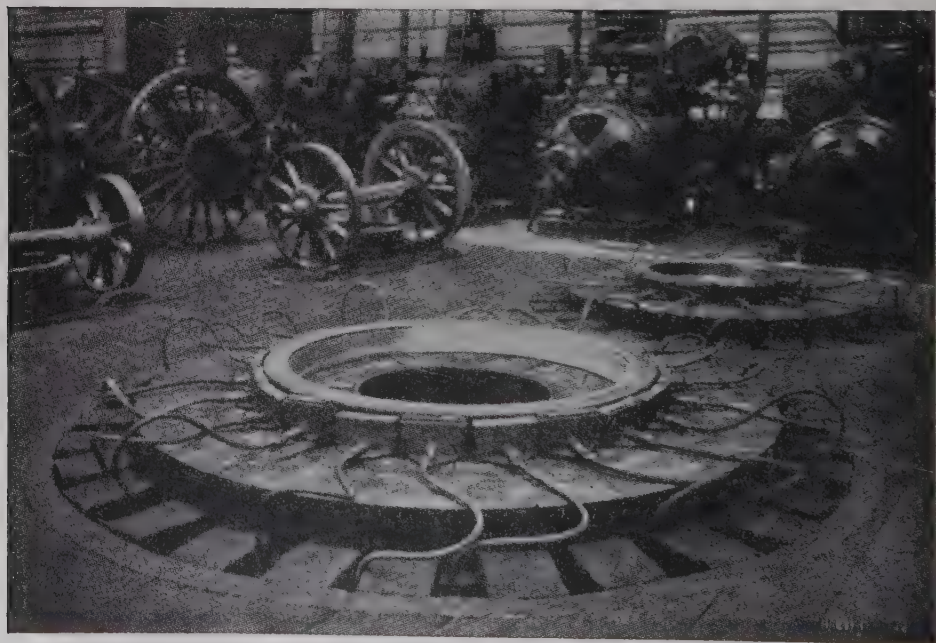


Fig. 14. How metal tires are shrunk on to the wheels of locomotives. Notice the two wheels on an axle in the left background; one has its tire on, the other has not yet been placed in position

over the cold rim (Fig. 14). When plunged in cold water the tire contracts and then has a tremendously effective grip on the wheel. Similarly, the castings of large guns are "shrunk" on the inner barrels. For the same reason, the rivets of boiler plates and ship plates are placed in position when hot. They are hammered home in this condition so that when cold they will have a firmer grip by contraction.

The same idea is the basis of the thermostat. In one form, used to control heat of incubators, strips of steel and aluminum are riveted together. As the strip bends with the heat it moves a lever, deflecting the warm air from the lamp outside the incubator. When the temperature falls the aluminum strip cools and straightens, allowing the lever to admit warm air again. In this way the temperature is maintained within required limits.

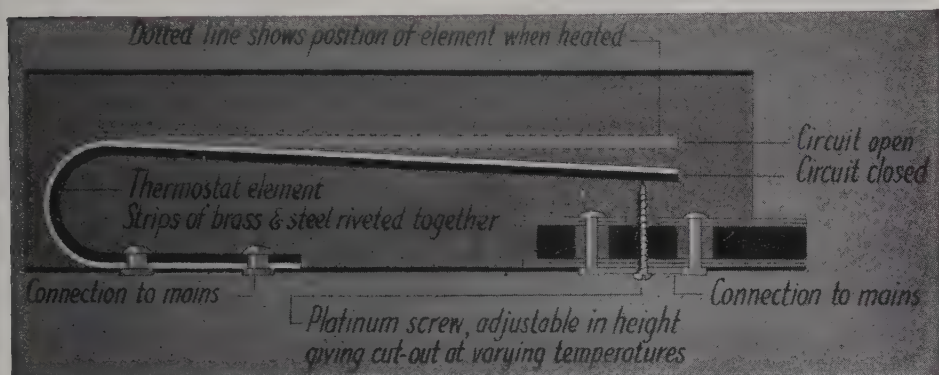


Fig. 15. How the expansion of different metals can be made to control an electric current

BIMETALLIC THERMOMETERS

Then again, expansion is used to measure temperature by means of thermometers. These may be of the mercury or alcohol type to which we have already referred, or of a type that relies on the fact that different metals expand unequally under the application of a given degree of heat. In these bimetallic thermometers, strips of iron and aluminum, brass and steel, or other metals are riveted together. As brass expands to a greater extent than steel, the bar will bend towards the steel side when heat is applied (Fig. 13). The amount of deflection—varying with the degree of heat—is read off on a graduated dial.

Another and more complex type of thermostat, consisting of two thin strips of brass and steel riveted together, can be made to control an electrically maintained temperature within certain prescribed limits. One of the strips is in contact with a platinum-tipped adjusting screw. When a rise in temperature causes the strip to bend up from the position shown in Fig. 15, contact with the platinum tip is broken and the current energizing the heating element is cut off.

Valuable as this expansive property is, it is also desirable to have a neutral substance that is not so affected by heat and cold. A substance of this kind is particularly required for

such purposes as the pendulum rods of clocks, and in certain measuring instruments.

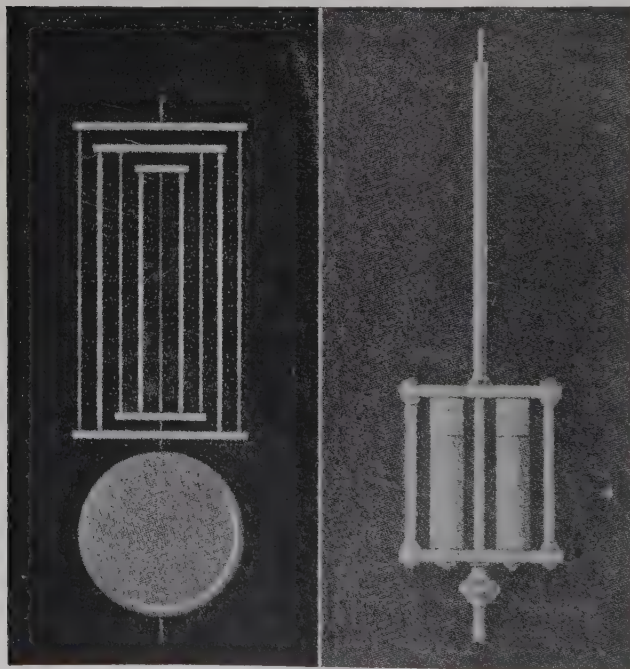
In the earlier days of clockmaking very little was known about the properties of metals, and for a long time it was a mystery why a clock should go faster in winter than in summer. Popular opinion was that in some way the sun affected the clocks in summer. Although this idea was correct in the abstract, the difference in the speed of a clock was actually due to the expansion or contraction of the metal of which it was constructed. In the hot days of summer the pendulum rod became longer by expansion, due to the increased temperature, and so

required longer to make its beat. In winter the reverse was the case and the clocks all ran a little fast.

THE MERCURY PENDULUM

It was left to George Graham, an English watchmaker and astronomer, to invent, in about 1720, the mercury pendulum. One or two jars of mercury replaced the usual weight on the pendulum. When the temperature increased in summer the mercury expanded upwards, thus counteracting the lengthening of the pendulum rod from the same cause (Fig. 16). With slight improvements, Graham's pendulums are still in use, for they enable a clock to keep accurate time.

A similar and perhaps very much better-known device was the gridiron pendulum (Fig. 17) invented in 1726 by another Englishman, John Harrison. This device consists of five rods of steel and four rods of brass, so arranged that the expanding brass rods raise the pendulum by as much as the expanding steel rods lower it. The principle will be completely clear from Fig. 18, where it is explained diagrammatically. The steel rod can only expand downwards, so lowering the "bob," while the brass rod can only expand upwards, so raising the "bob B." By carefully arranging the downward expansion



Figs. 16 and 17: Fig. 16 (right) Graham's mercurial pendulum. The two glass cylinders contain mercury compensating for increased temperature. Fig. 17 (left) Harrison's gridiron pendulum. The thinner rods are steel, the others brass. The steel rods expand downwards, the brass rods upwards.

to equal the upward expansion, the pendulum length A-B is kept constant.

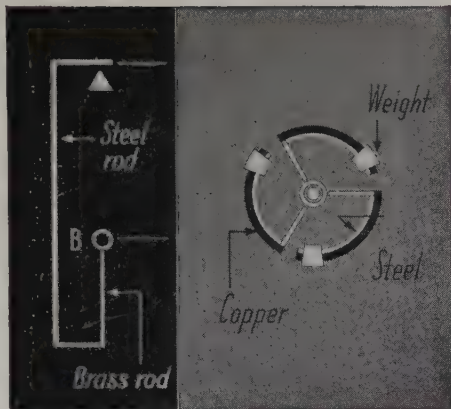
A somewhat similar use of the expansion of dissimilar metals is found in the balance wheels of some watches. This method was introduced by Thomas Earnshaw in the latter part of the eighteenth century. The balance wheels of a watch oscillate under the influence of a hair spring, and naturally the number of oscillations varies according to the dimensions of the wheel. A rise in temperature causes an increase in the dimensions and so causes the watch to lose time.

This is counteracted by making the circumference of the wheel of dissimilar metals (Fig. 19), the outer one being more expansible than the inner. The rim is made in three parts, each supported by a spoke or arm of the wheel. Thus when the temperature rises, the end of the segment of the rim nearest the supporting arm is pushed outwards from the center by the expansion of the arm. At the same time, the other end turns in towards the center, owing to the greater degree of expansion of the outer strip of metal. Exact compensation is obtained by accurate adjustment of the weights fixed to each segment by screws.

Subsequent researches produced an ideal metal for clock pendulums. This is an alloy of 64 per cent steel and 36 per cent nickel, known as "invar steel." Its linear coefficient of expansion is only 0.0000009, 13 times less than that of either of its constituents. A 39-inch pendulum of invar heated 1° F. expands about 0.00002 inch.

CAPACITY FOR HEAT

Temperature, as we have pointed out, is a measure merely of the in-



Figs. 18 and 19: Fig. 18 (left). The grid-iron pendulum. The brass rod expands upwards so raising the weight and the pendulum is thus kept in a constant position. Fig. 19 (right) watch balance wheel. The positions of the weights insure correct compensation.

tensity of heat or of molecular motion and not of the total heat energy. The quantity of heat is measured in a unit called the calorie, defined as the quantity of heat needed to raise the temperature of 1 gram of water 1° C. Engineers use a similarly defined unit, the British thermal unit, or B.T.U. This is the amount of heat required to raise the temperature of one pound of water 1° F. and is equal to 253 calories.

The number of calories of heat used to raise the temperature of one gram of a given substance 1° C. is its specific heat, or heat capacity. From the definition of the calorie it can be readily seen that the specific heat of water is one calorie. Each substance has its own characteristic specific heat. If all of the heat energy absorbed by a substance was used merely to raise the energy of motion of its molecules, that is, the temperature, then the same number of cal-

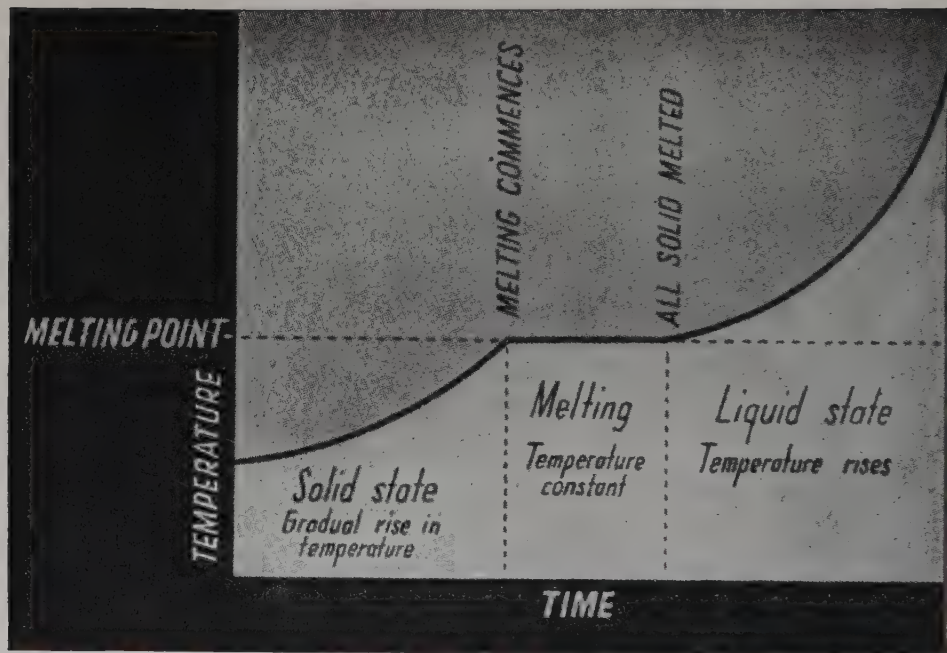


Fig. 20. Illustrating the principle that heat may be absorbed by a substance without any change of temperature. See text on page 263 for full explanation of this peculiar phenomenon

ories of heat would be required to raise the temperature of the same number of molecules of different substances the same amount. This, however, is not the case. In general, the simpler the molecules, or, in other words, the smaller the number of atoms which each of the molecules of a substance contains, the smaller is the heat capacity of that substance. Part of the heat supplied to a given substance is stored as potential energy within its molecules, and the rest increases the molecular kinetic energy, that is, the temperature. In a like manner, when the substance cools, part of the heat which is given off comes from the potential energy within the molecules and part comes from the kinetic energy of molecular motion.

If we mix a pint of water at 50° F. with a pint at 100° F. we shall have two pints; the temperature of which the thermometer will show to be 75° . On the other hand, if we mix a quantity of mercury at 100° with an equal quantity of water at 40° , the temperature of the whole will not be 70° , but 60° , the mercury losing 40° and the water gaining 20° , according to the thermometer. Yet the additional 10° lost by the mercury must be in the water, which we thus see has a greater capacity for storing heat than mercury. To put it in another way, a larger quantity of heat is required to raise water to a given temperature than is required by mercury. It is because mercury has what is called a low *specific heat* that it is used in thermometers, for it comes rapidly to

the temperature of its environment. On the other hand, water is unsuitable for thermometers because it stores much heat, and is heated and cooled only slowly.

When a change of state occurs, that is, when a solid melts or a liquid is vaporized — or vice versa — energy changes are always involved. Melting and vaporization are processes which generally involve the separation of molecules against the force of their mutual attraction. Thus work has to be done and energy supplied to accomplish these changes. This energy is stored in the melted solid or the vaporized liquid as potential energy, and reappears again when the liquid freezes or the vapor condenses.

Thus, when a solid melts, or when a liquid boils, it takes in a certain amount of heat without alteration in the measurable temperature. No change of state is possible without absorbing or giving out heat. It requires 80 calories of heat to melt one gram of ice, and the melted ice (water) will have a temperature of 0°C . Similarly, 540 calories are required to convert one gram of water into steam, without any change in its temperature. When these changes are reversed the same amount of heat would be given out without any change in the temperature (Fig. 20).

MELTING AND FREEZING

The molecules in the crystals of a solid are held in fixed positions by forces of attraction. Working against these forces is the kinetic energy of the molecular vibration which determines the temperature of the solid. At any temperature there is a balance between the forces of attraction pulling the molecules together and the thermal vibration which tends to drive

them apart. This balance determines the average distance between the molecules. As the temperature rises, the increased vibration increases this distance and the solid expands. Finally a temperature is reached when the molecular vibration is just great enough to break down completely the regular arrangement of the molecules, and the crystal melts.

Now the forces of attraction depend upon the particular kind of molecule of which the crystal is built. Hence these forces are not the same between the molecules of different substances. Hence the temperature at which the crystal structure disintegrates is characteristic of the substance. Each substance, in other words, has its own melting point. At the melting point the thermometer will remain stationary as long as there is any solid left unmelted. Although heat is being absorbed from some external source, its energy is spent in doing the work of separating the molecules from one another. Only after this work has been done does the energy absorbed go to increasing the molecular kinetic energy, that is, the temperature.

The range of melting points of solids is a very wide one. At one end of the scale is helium, which melts at -272°C .; and at the other is carbon, melting at $3,500^{\circ}\text{C}$. Helium is a remarkable element whose atoms are most unsociable. They not only refuse absolutely to combine with the atoms of other elements but will have almost nothing to do with one another. The helium atomic structure is so symmetrical that the force of attraction between its atoms is the smallest interatomic force known. Temperatures approaching absolute zero must be attained before it may be liquefied. Its solid form melts at less than a

degree above absolute zero. To indicate the wide range of melting points of other substances, consider the following examples: benzene, 5.5° ; sulphur, 113° ; zinc, 419° ; aluminum, 660° ; silver, 961° ; gold, $1,063^{\circ}$; copper, $1,083^{\circ}$; iron, $1,535^{\circ}$; and platinum, $1,755^{\circ}$ C.

A liquid freezes at the same temperature at which its solid form melts. In fact at the freezing point the solid and liquid states of a substance can exist simultaneously. If the temperature is maintained ever so slightly above this point, the solid form will melt, or if it is slightly lowered below this point, the liquid will quickly freeze over.

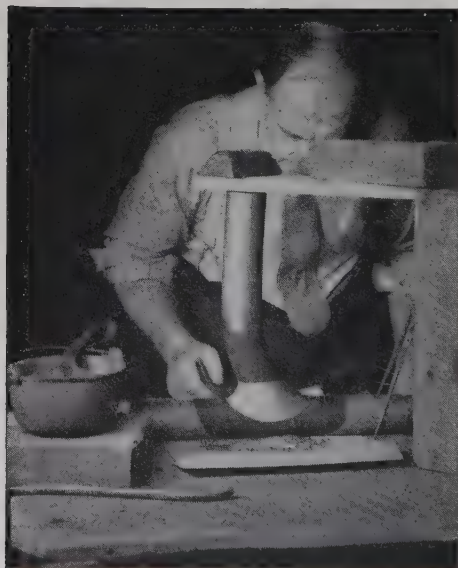
The presence of impurities dissolved in a liquid lower its freezing point. The greater the concentration

of the impurities the greater will be their effect. Thus salt water freezes at a lower temperature than fresh water. Furthermore, as ice crystallizes out of salt water the concentration of the salt increases and the freezing point is progressively lowered. A solution, therefore, has no sharp freezing point as has a pure liquid. Advantage may be taken of this fact by the plumber (Fig. 21). Pure liquid lead freezes sharply at 327° C. To seal a joint with pure lead would be decidedly inconvenient. Mixing lead and tin in equal parts, however, gives "plumber's solder," an alloy that begins to solidify at 220° C. but is not hard until its temperature is 180° C. This gives the plumber a sufficient margin of time to "wipe," or make the familiar bulbous joint.

Very low melting alloys of several metals find use in fuses to safeguard electric circuits from overload, and as plugs in automatic fire sprinklers. One such alloy is Wood's metal, composed of 50 per cent bismuth, 25 per cent lead, 12.5 per cent tin, and 12.5 per cent cadmium. This alloy melts at about 70° C., that is, below the boiling point of water. The melting points of the pure metals of which it is composed are: lead, 327° ; tin, 232° ; cadmium, 321° ; and bismuth, 271° C.

EVAPORATION AND VAPOR PRESSURE

When water is left in an open vessel it evaporates and eventually none is left. This is a property of all liquids and is another evidence of molecular motion. From time to time molecules shoot out from the surface and make good their escape from the attractive force of their fellow molecules. Naturally the speed with which a liquid evaporates increases with the temperature, or as, in other words, its kinetic



Wurtz Bros.

Fig. 21. Because pure lead solidifies at such a high temperature the plumber uses a mixture of lead and tin to seal this pipe joint. The lower solidification point allows time for an efficient and neat-looking wipe

energy increases. A liquid in a stoppered bottle, however, does not seem to evaporate. This is not the case, for the liquid is evaporating at the same rate as in an open vessel. In the stoppered bottle, however, the vapor accumulates; and its molecules return to the liquid whenever they strike its surface. This process is the reverse of evaporation and is called condensation. The rates of condensation and evaporation in a closed bottle are equal; that is, in a unit of time equal amounts of vapor have condensed and liquid have evaporated. Such a system, in which two opposite changes are taking place at equal rates, is said to be in equilibrium. Under such circumstances the net result is the same as if no evaporation were taking place. At equilibrium the concentration of the vapor, which is the number of molecules in a unit volume, remains constant; and the pressure which these molecules exert remains constant also. This is the vapor pressure of the liquid, although it must be remembered that it is the vapor in equilibrium with the liquid which is exerting the pressure. When the temperature is raised, the concentration of the vapor at equilibrium increases and the vapor pressure rises.

When the temperature has risen to such a degree that the vapor pressure becomes equal to the pressure of the atmosphere, the liquid boils (Fig. 22). Let us see why this is so. Boiling is recognized by the appearance of bubbles of vapor within the liquid. These are in equilibrium with the liquid and so the pressure inside them is the vapor pressure. The pressure on the bubbles is that of the atmosphere, so that if the atmospheric pressure were greater than the vapor pressure of a liquid at a given temperature, bubbles

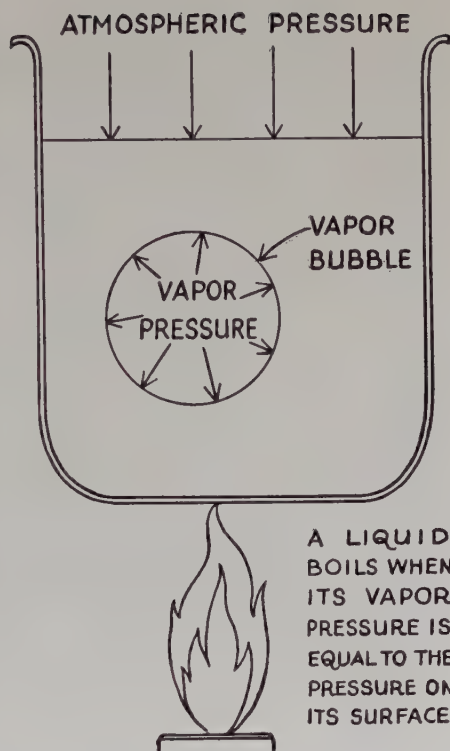


Fig. 22. Illustrating the principle governing a liquid's boiling point. See text for full explanation of diagram

of vapor could not form. A liquid boils, therefore, when its vapor pressure becomes equal to the pressure on its surface.

The rate at which different liquids evaporate at the same temperature depends on the relative strength of the forces of attraction between their molecules. The weaker this force, the greater will be the rate of evaporation. Ether evaporates faster than water and water faster than mercury. The force of attraction between ether molecules is the lowest; between water molecules it is greater; and between those of mercury it is greatest of the three. At a given temperature,

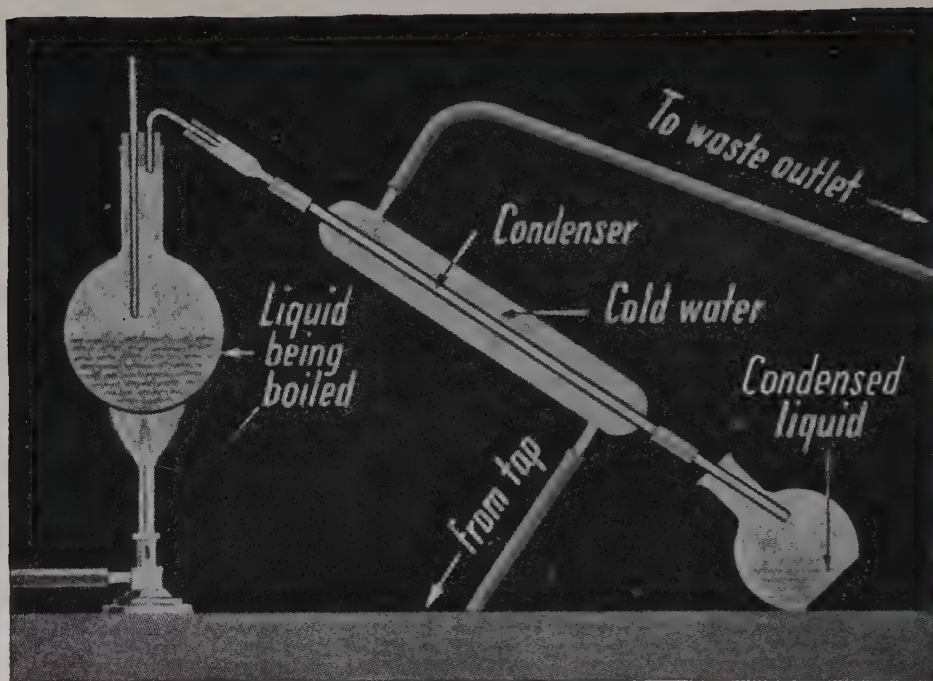


Fig. 23. The principle of condensation. Water is boiled in one flask and the steam in passing through a tube surrounded by cold water is condensed back into water. Fresh water can be obtained from sea water, and many other liquids can be purified or distilled in this way

therefore, ether has the greatest vapor pressure and the lowest boiling point. The higher the vapor pressure the lower the temperature at which it becomes equal to atmospheric pressure.

BOILING POINTS

The temperature at which a liquid boils depends upon the pressure on its surface. If this pressure were increased the liquid would boil at a higher temperature and, if decreased, at a lower temperature. Everyone knows that the atmospheric pressure is less at the top of a mountain than at sea level. Hence water boils at a lower temperature on a mountain top. At first sight it would seem more eco-

nomical to cook potatoes in high altitudes but it must be remembered that the boiling process does not cook the food.

Cooking involves chemical reactions the rate of which depends on the temperature and not on the boiling. Water boils at 85°C . at the top of Mont Blanc (15,781 feet). Since a decrease of 10°C . roughly doubles the time necessary for the completion of a chemical reaction, it must take about three times as long to cook potatoes as at sea level. For this reason in the higher altitudes—as in the plateaus of the Andes, for example—all food is roasted or baked; boiled eggs are unknown. At the St. Bernard Hospice (8,600 feet) the monks prepare

fried or roasted food in place of boiled dishes. If only more people lived at high altitudes, what a fertile field such regions would be for a pressure-cooker salesman! In such vessels water may be heated beyond the boiling point, as the pressure on its surface mounts with the temperature.

DISTILLATION

Different liquids have their own boiling points because of the difference in the forces of attraction between their molecules. As in the case of melting points, these boiling points show some extreme differences in temperature. Hydrogen boils at -253°C ., chlorine at -34° , water at 100° , mercury at 357° , sulphur at 445° , silver at $1,995^{\circ}$, and carbon at $4,200^{\circ}$. This difference is used exten-

sively in the purification of liquids and in their separation by the process of distillation. Since the impurities dissolved in water are mainly solids which are not volatile at its boiling point, water may be boiled away from them in a still and the vapors condensed in a cooling device called a condenser (Fig. 23).

Crude petroleum is a mixture of many liquid and some solid hydrocarbons—compounds of hydrogen and carbon only—all mutually dissolved in one another. These are vaporized in a still and the vapors passed into the bottom of a fractionating column. Here they condense at different levels (Fig. 25). Those corresponding to the higher boiling liquids condense at lower levels than those of lower boiling points. In this manner a fraction-

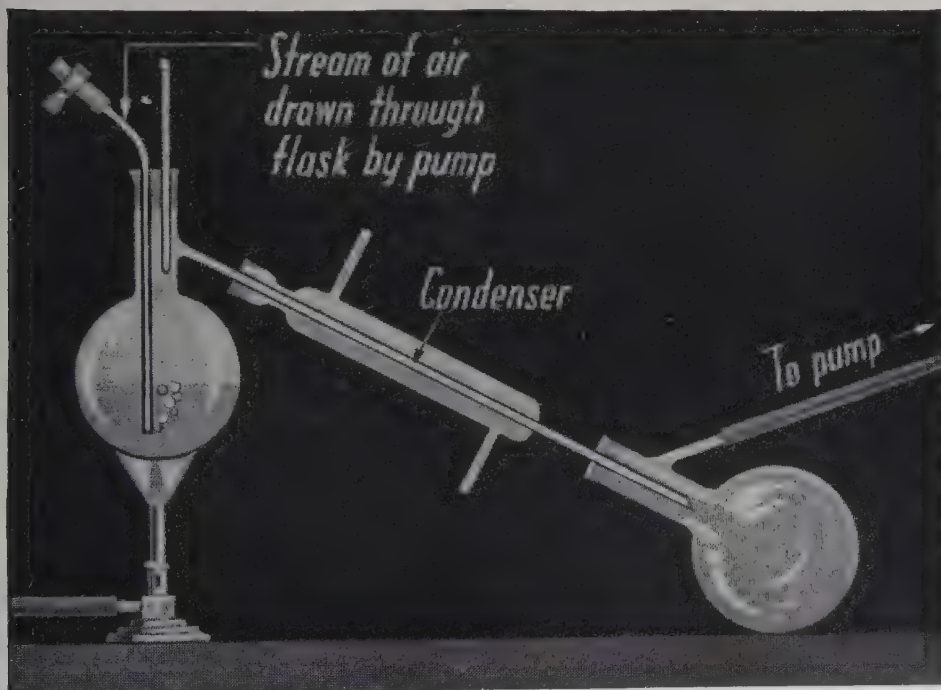


Fig. 24. The principle of distillation under reduced pressure or in a vacuum. See text for complete description

Typical FLOW CHART tracing crude oil from well to finished product.

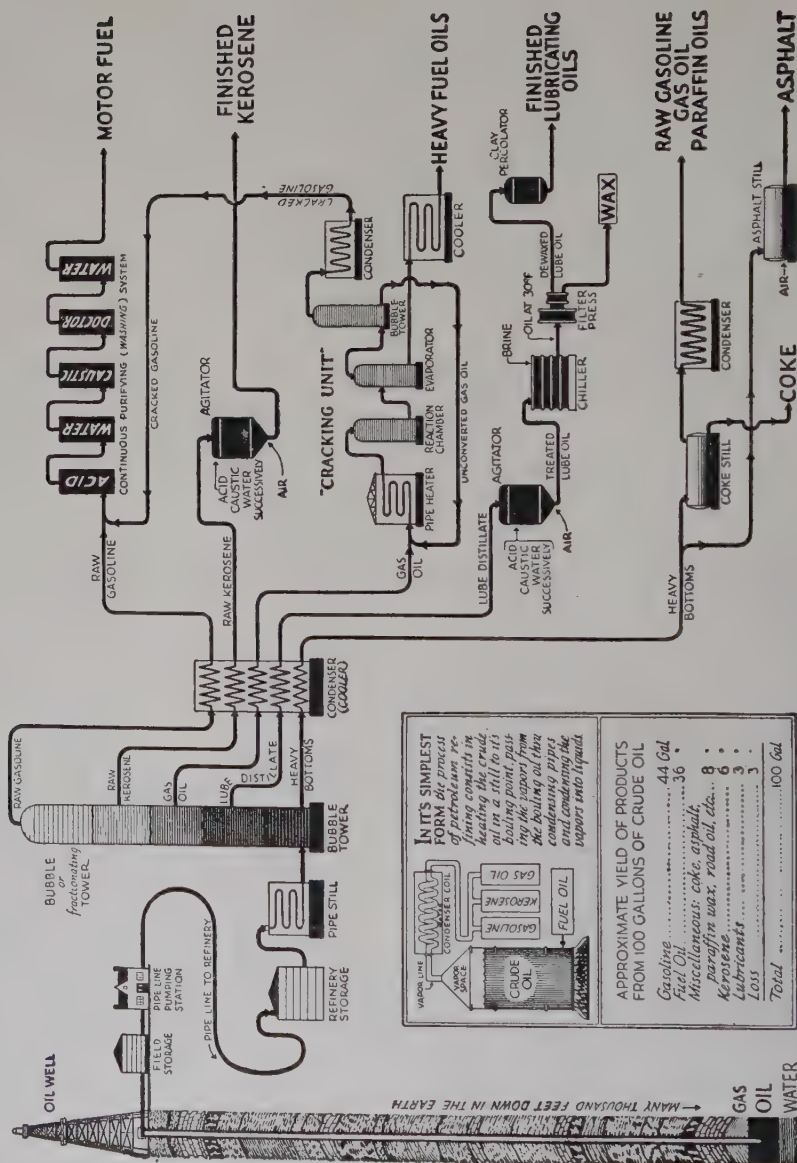


Fig. 25. Diagram showing the fractional distillation of crude oil

ation is effected. These fractions may be familiar to you. At the top of the column the most volatile gasoline fraction condenses, followed at lower levels by kerosene, gas oil, lubricating (lube) oils, and finally the delightfully named heavy bottoms. The gasoline fraction makes up only about 25 per cent of the products of distillation and the less useful gas oil fraction, 40 per cent. The conversion of the gas oil fraction into gasoline is accomplished by the so-called cracking process, invented in 1914 by Burton (Fig. 26). The gas oil is heated in pressure stills far above its normal boiling point at atmospheric pressure. Its large molecules are cracked in half

into smaller molecules of hydrocarbon boiling in the gasoline range. By this process the yield of gasoline from a given amount of crude oil has been doubled.

Some liquids decompose chemically at temperatures lower than their normal boiling points. It would seem that these could not be purified by distillation. However, by placing them in a still connected with a vacuum pump (Fig. 24) the pressure on their surfaces can be reduced to such an extent that they may be boiled at temperatures below those at which they decompose. By this means many precious organic liquids may be completely purified.



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Fig. 26. A battery of cracking stills at a Whiting, Indiana, petroleum refinery producing gasoline for use as a motor fuel. The cracking process, invented by Burton in 1914, has doubled the gasoline yield of a given quantity of crude petroleum

MECHANICAL REFRIGERATION

The processes of boiling and evaporation absorb heat, since they involve a separation of molecules against the force of their mutual attraction. These changes produce a cooling effect since they involve a conversion of heat into potential energy. This fact is at the basis of the design of all mechanical refrigerators.

The refrigerant is a substance which can be easily liquefied by pressure at room temperature, yet which has a high rate of evaporation and a high heat of vaporation. Many such substances are available, e.g., sulphur dioxide, which can be prepared readily by the combustion of elementary sulphur, or freon, a compound derived from natural gas (CH_4) by substituting chlorine and fluorine atoms for its four hydrogen atoms. The latter is practically odorless and is not poisonous. Hence leaks do not liberate a dangerous gas.

The vapor of the refrigerant is compressed, a process which liberates heat so that the refrigerant is not liquefied by the process. The warm, compressed vapors pass into the cooling coil, or condenser, over which air is blown by a fan, or they are cooled by the simpler process of placing the coils on the outside of the refrigerator in the back or on top where the refrigerant is cooled by the air of the room. In this way the heat due to the initial compression is removed and the temperature is lowered to such an extent that the refrigerant liquefies. The liquid collects in a suitable reservoir from which it passes through the expansion valve into the evaporator, where the pressure is kept low. Rapid evaporation and expansion result from the sudden decrease in

pressure. Since both these processes absorb heat from the surroundings, refrigeration results. The vapor at low pressure returns to the compressor and the same cycle is repeated.

The automatic device, by which the motor is turned on when refrigeration is needed and turned off when the refrigerator is sufficiently cool, is very ingenious. A sample of the liquid refrigerant in equilibrium with its vapor is placed in a closed tube in the space to be cooled. The other end of the tube is connected to a bellows which actuates the switch. The pressure in the tube is, of course, the vapor pressure of the refrigerant at the temperature of the refrigerated space. As the temperature rises, the vapor pressure rises also and the bellows expands, thus closing the switch. The machine starts running and lowers the temperature. As the temperature falls, the vapor pressure is reduced and the bellows contracts. When the temperature has been lowered sufficiently, the bellows contract and the refrigerator stops running.

LIQUEFACTION OF GASES

The demand for compressed gases by our modern industry has become so great that trucks laden with heavy steel cylinders full of these gases have become a familiar sight on city streets. Cylinders of compressed oxygen and acetylene are shipped to welders (Fig. 27); of compressed carbon dioxide to makers of carbonated beverages; and of chlorine to the city water plant to disinfect our drinking water. These cylinders look more or less alike on the outside except for the distinguishing color in which they are painted. However, inside the iron walls, there is an important difference. Within the cylinders of carbon dioxide



Linde Air Products Co.

Fig. 27. The two gas cylinders contain oxygen and acetylene gas, the oxygen being in the larger of the two. From these two cylinders comes the oxy-acetylene flame which is often used for cutting and demolition work, as well as for the accurate shaping of metals

and chlorine, for example, we should find these substances in the liquid state in equilibrium with their vapors. The pressure in these cylinders is, therefore, always equal to their vapor pressures as long as any liquid remains. At 20°C . (68°F .) the pressure is 810 pounds to the square inch in the carbon dioxide cylinder, and 99 pounds to the square inch in that of chlorine. On the other hand, in cylinders containing oxygen and hydrogen there is no liquid despite pressures as high as 2,000 pounds to the square inch. The explanation of this difference lies in an exact understanding of what is meant by the term critical temperature.

If a liquid is confined in a closed vessel, it soon comes to equilibrium with its vapor and the latter exerts the characteristic vapor pressure corresponding to the temperature. When the temperature is raised, the system is out of equilibrium for a short time during which the rate of evaporation goes faster than that of condensation. As a result, more liquid becomes vapor and the concentration of the vapor increases. This results in an increase in the rate of condensation until both rates eventually become equal again. Since the concentration of the vapor has increased, it has become more dense and exerts a higher vapor pressure. However, the

TABLE I—CRITICAL TEMPERATURES AND PRESSURES

<i>Substance</i>	<i>Critical temperature °C.</i>	<i>Critical pressure atm.</i>
Water	374.0	217.72
Sulphur dioxide	157.2	77.7
Chlorine	144.0	76.1
Ammonia	132.4	111.5
Carbon dioxide	31.1	73.0
Methane	−82.5	45.8
Oxygen	−118.8	49.7
Argon	−122	48
Nitrogen	−147.1	33.5
Neon	−228.7	25.9
Hydrogen	−239.9	12.8
Helium	−267.9	2.26

molecules of the liquid are moving with greater kinetic energy, due to the temperature increase, so that its molecules are farther apart and hence its density is less than at the lower temperature. As the temperature is further raised, the density of the vapor grows and that of the liquid diminishes, until finally both densities are equal. Under this unique condition the same kind of molecules are the same average distance apart in both the liquid and the vapor, hence there is no difference between the two phases. The surface, which has hitherto marked a difference in properties, now disappears and the two phases become one. The temperature at which this happens is a characteristic of a given kind of substance and is called its critical temperature. The table gives the critical temperatures of some of the common vapors and gases. The pressure in the closed vessel at the critical temperature is called the critical pressure.

Above its critical temperature a substance remains a gas however highly it may be compressed. To

liquefy a gas, therefore, it is first necessary to cool it to below its critical temperature. This is usually accomplished by a series of expansions from a higher to a lower pressure. The process by which air may be liquefied may be followed by referring to the somewhat simplified diagram of a liquid-air machine shown in Fig. 29. The gas is first compressed, and the heat developed by this process is removed by passing the gas through cooling coils. It then is allowed to expand through an expansion valve, C, into the chamber, D, which lowers its temperature. It leaves the chamber through the pipe, B, which encircles the smaller pipe, A, through which a new portion of compressed gas is passing on its road to the expansion valve. In this way each portion of compressed gas is cooled further by the gas leaving the chamber and arrives at the expansion valve at a lower temperature than the gas which preceded it. The temperature, therefore, is progressively lowered in the chamber until the critical temperature is passed.

This occurs in the case of air at -140.7°C . The pressure in the chamber is sufficient to liquefy the air.

Air in the liquid state is an extremely interesting material. It is a solution of the two elements, oxygen and nitrogen. Liquid oxygen boils at atmospheric pressure at -182.5°C , and nitrogen at -195.5°C , so that when the liquid air warms spontaneously, liquid nitrogen boils off first and a separation of the two elements can be effected. This process is the basis of the method by which relatively pure oxygen is obtained for industrial purposes, e.g., oxyacetylene welding. Vast quantities of nitrogen are needed for nitrogen fixation, that is the conversion of it into nitrogenous

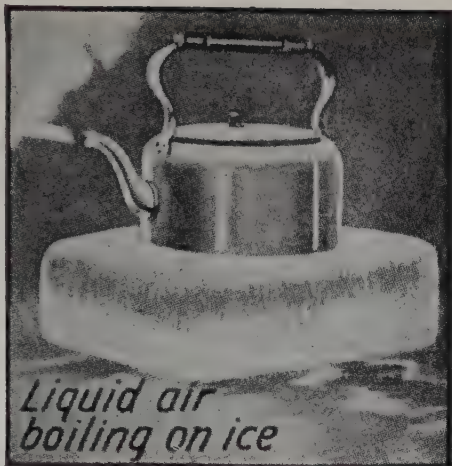


Fig. 28. Liquid air is so cold that it would boil if placed on a block of ice. Principle is explained on this page

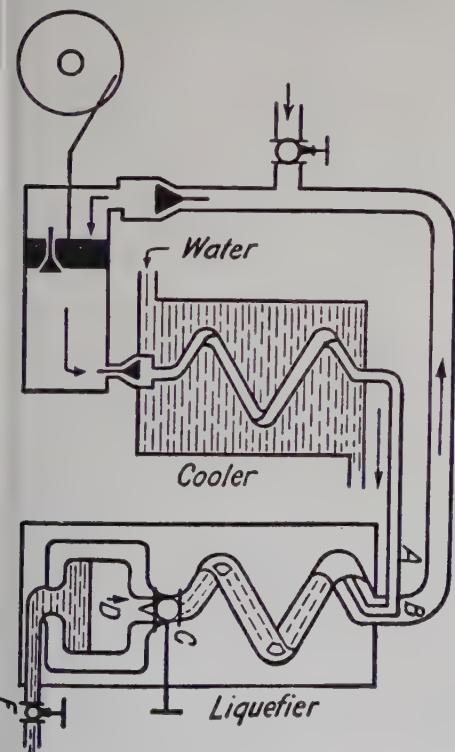


Fig. 29. Simplified diagram of a liquid-air machine

compounds important as fertilizers, and for the manufacture of explosives. In 1932 over 2,086,301,000 cubic feet of oxygen, valued at \$24,000,000, was produced in 156 plants from liquid air. Since the inert gases, mainly argon and neon, which are also found in the earth's atmosphere, remain as gases under the conditions which liquefy the oxygen and the nitrogen. These may be separated and sold to the manufacturers of the gas-discharge type of illuminated signs.

Liquid air is so extremely cold that it boils away violently on a block of ice (Fig. 28); that it condenses water vapor as a fog in the air nearby; and that rubber and flowers immersed in it become as brittle as glass. It may be kept for several hours in vacuum-jacketed bottles since heat energy cannot pass through the vacuum from the surroundings. As the nitrogen boils away, the delicate blue color of liquid oxygen becomes more pronounced. This blue liquid is tremen-

dously concentrated oxygen and substances burn with explosive violence when soaked with it. An extremely high explosive may be prepared by combining liquid oxygen and powdered charcoal.

HELIUM

Helium is a gaseous element which occurs in traces only in the earth's atmosphere. It was discovered in the corona of the sun forty years before its presence was established on the earth. A yellow line appeared in the spectroscope through which the astronomer Janssen was observing the sun's corona during the solar eclipse of 1868. The line had not been observed in the spectra of any of the known elements. In 1895, the British

chemist Ramsay discovered it in the gas given off when radioactive minerals are treated with acid. This gas, which is absolutely chemically inert and forms no compounds, is the ideal gas with which to fill dirigibles, as it is noncombustible and has the lowest density of any gas except hydrogen. The latter, however, is extremely combustible as was amply demonstrated when the Hindenburg burned. The discovery of helium in certain natural gas wells in this country has provided an ample source of this gas. Since the critical temperature of helium (-267.9°) is far below that of methane (-82.5°), the principal constituent of natural gas, the latter may be liquefied and thus separated from the gaseous helium.

CHAPTER 13

SOUND

SOUND—or, more precisely, a sound wave—may be generated by a vibrating movement caused by the setting in rapid motion of the particles of an elastic body. Sound itself does not exist in the outer world, for it is a sensation that makes itself felt within the brain when the vibrations strike the eardrum and stimulate certain of the more sensitive nerves of the body.

Sounds are produced by anything that will cause vibrations rapid enough to make the air vibrate, such as knocking on a door, firing a gun, or scraping a string with a bow. The vibrations of a tuning fork produce melodious sounds as do those of a column of air in a pipe organ. Some things vibrate too slowly to produce sounds—as, for instance, our legs when walking, a windmill, or the spokes of a bicycle wheel.

It is not difficult to actually see the vibrations of many bodies when they are producing sounds—particularly the

strings of musical instruments, large bells, or membranes of drums. If suspended pith balls are brought near to a bell just after it has been struck, or near a wine glass that is stroked by a violin bow, the balls will at once commence to oscillate, thus giving evidence of the vibration of the air in the vicinity. Fig. 1 illustrates the principle involved.

Sound vibrations may be rendered visible in several ways. One of the earliest experiments in this direction was demonstrated in 1862 at the London Exhibition by Rudolph Koenig. He showed how a flame can be made to rise and fall in sympathy with sounds, and by means of a series of rotating mirrors he was able to make drawings of the characteristic outlines of various sounds (Fig. 2). A little later, although the science of photography was in its infancy and its applications were very limited, it was found just possible to photograph Koenig's flames, and the results were

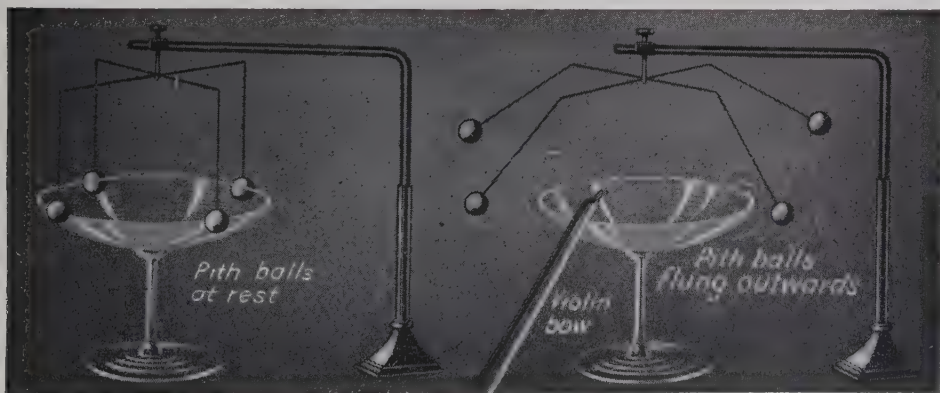


Fig. 1. When pith balls are suspended near the edge of a wine glass that is stroked by a violin bow, they will fly outwards, thus proving air vibration

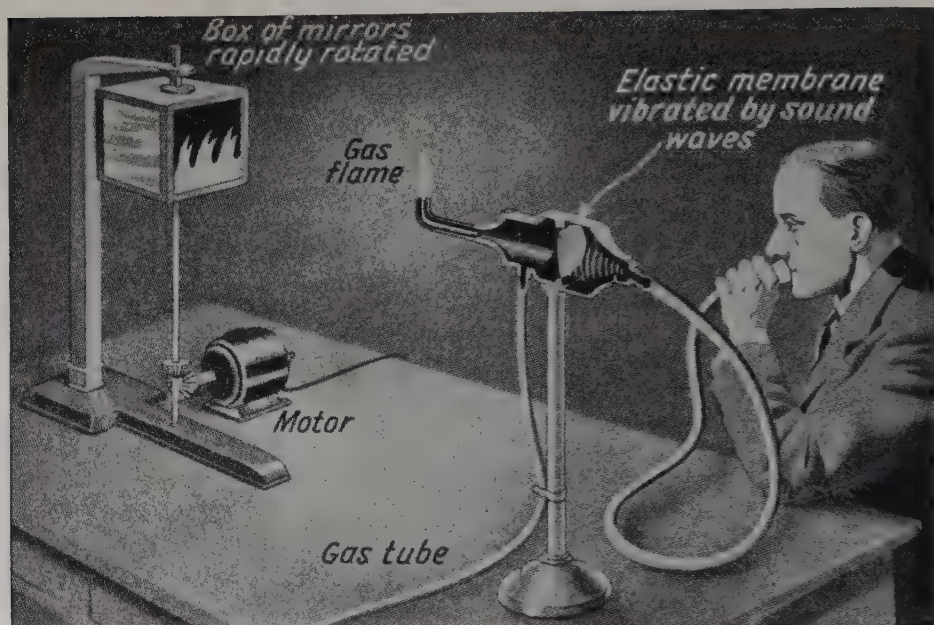


Fig. 2. An early experiment to make sound waves visible. Sound vibrations impinging upon a membrane will distort a gas flame. Variation in the flame may be observed in rotating mirrors. This experiment was demonstrated by Rudolph Koenig at the London Exhibition of 1862

regarded as a great achievement. In 1897, by using an acetylene flame instead of gas, better-defined photographs were obtained. Of course, in more recent years progress in research has been very rapid so that Koenig's experiments, although still of laboratory interest, are now regarded as somewhat crude; yet at the time they were considered among the marvels of science.

Another experiment by which sound vibrations can be rendered visible is to sprinkle a vibrating body with fine sand or powder. In this way, sonorous vibrations may be shown by using a violin bow on the edge of a sheet of glass, held by a small wooden vice or placed on a stand. The glass is sprinkled over lightly with lycopodium powder—a very fine powder

obtained from the spore cases of certain plants. The glass plate emits sounds that vary in accordance with the vibrations. By applying the bow and touching the glass plate at various points along the edges, a wide variety of beautiful figures can be produced (Fig. 3), for powder collects along the "nodal lines" where there is no motion at all of the glass.

A similar symmetrical arrangement will be seen if sand is sprinkled over a membrane stretched over the mouth of a funnel. A cord, passed through the membrane and held there by a knot, is drawn through the fingers (previously smeared with rosin), thus causing the membrane to vibrate. Similarly, a thin membrane or piece of tracing paper, stretched over a circular wooden frame and sprinkled

over with sand, will show the vibrations of a tuning fork or bell held near to it.

MOTION OF SOUND WAVES

When the motion of a sound wave is sufficiently rapid to affect the ear—that is to say when the regular vibrations amount to about 40 a second—we hear a more or less pleasing sound or a musical note. On the other hand, a single blow, or an irregular motion of air particles, results in a “noise,” as distinct from a harmonious sound.

Music has been described as “a noise that is less objectionable than other noises,” an epigrammatic definition that nevertheless states a basic

fact. All “noises” and sounds are radiated from their source and transmitted to the ear in an exactly similar manner. The clatter of a street car or a train going over railway points; the noble tones of an organ; the majestic tone of brass instruments; and the singing tones of wood-wind, and stringed instruments in a symphony orchestra—all are made audible by exactly the same means. The difference between a musical note and a noise is that the waves from the former are regular and of uniform length, whereas from the latter they are a more or less confused mixture of varying lengths. They form an irregular succession of shocks, as it



Fig. 3. When a glass plate is stroked by a violin bow, it emits vibrations. These may be rendered visible by sprinkling the plate with fine powder. Different patterns are produced by varying the strokes and by gripping the plate between thumb and finger in different places

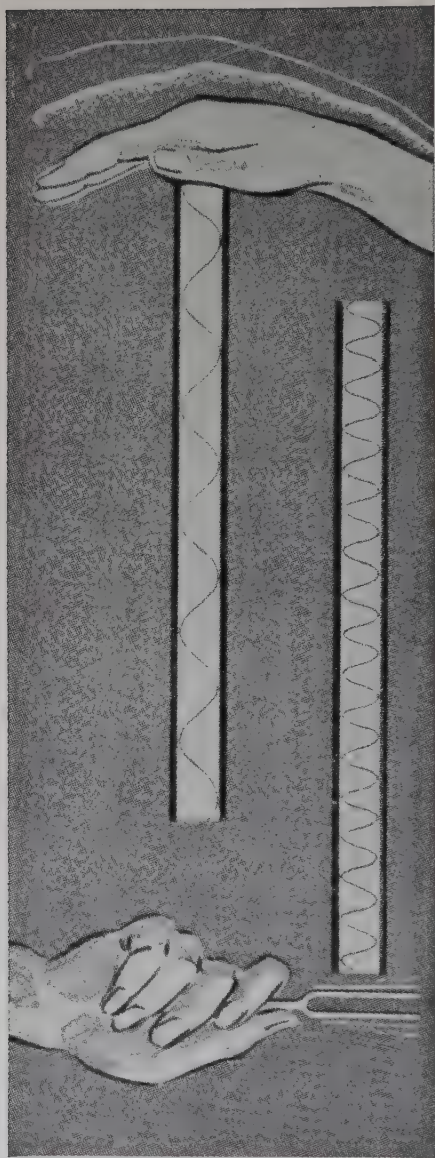


Fig. 4. (Top) A tuning fork will give rise to a series of vibrations producing a musical note in a pipe. Similarly (bottom), if the end of an open pipe is struck a series of vibrations is set up within the pipe. Use of this simple fact is made in construction of the most complicated musical instruments

were, that cause a “jarring” rather than a “soothing” effect to be communicated by our auditory nerves. Miller, who has devoted considerable time to the subject, has defined a noise as “a sound that is of too short duration or too complex in structure to be analyzed by the ear.”

There are several methods of generating musical sounds. For instance, if we take a length of piping, open at both ends, and strike one end with the palm of the hand (Fig. 4), we produce a hollow and musical “plop.” If the end is repeatedly struck in this manner and the speed of striking gradually increased, the “plops” increase in number. If the striking takes place a great many times a second, the “plops” merge into each other and give the effect of a continuous note. The sound is caused by the hand forcing air into the end of the pipe and slightly compressing the air at that end. As air is an elastic substance this wave of compression passes along the tube and emerges from the other end where—as it is no longer restricted by the tube—it spreads through the air in the form of waves of compression.

Similarly, if we provide some means of agitating, or beating, the air very rapidly at the end of the pipe—as with a tuning fork—a note of a certain pitch is obtained (Fig. 4). If the impulses are increased in number per second, the sound will rise in pitch—that is to say the note rises in proportion to the increase in beats. Whether a note is high or low is determined by the rapidity of the beats or air waves. For simplicity, these air waves may be termed “vibrations,” as in all forms of musical sound production some mechanical vibration is used.

BASIS OF THE PIPE ORGAN

The principle we have discussed is the basis of the organ, which consists of a number of pipes. Through these wind from a compressed air box is passed by opening a pallet. The air rushes through and over a lip, by striking which it sets up vibrations in the pipe (Fig. 5). Different sizes of pipes and different materials give different notes and different effects.

Other ways of producing musical notes are by vibrating a string by striking it with a hammer, as in a piano; plucking a string, as with a harp; vibrating a reed by blowing past it, as with such wood-wind instruments as the clarinet or oboe; or by vibrating an air column in a tube or pipe, as with brass instruments (trumpets, trombones, etc.).

If an elastic band is stretched between the hands and someone plucks it, a dull, low note will be heard. It has very little power, however, since the waves set up, although rapid, are small. To increase the "pitch" of the note—but not its volume—it is only necessary to stretch the band tighter between the hands. This has the effect of increasing the number of vibra-

tions per second that the band makes when it is plucked.

To increase the volume of the note, the band can be stretched on a frame as a string is stretched in the case of a harp, or on a hollow body, as in the

violin or cello. In these instruments the strings are usually of gut, silk, or wire, or a combination of gut and wire. In the case of the violin and similar instruments, the strings are stretched over a wooden bridge placed on the hollow body of the instrument, which is reinforced by a sound post to take the pressure from the stretched strings (Fig. 8). When the string is vibrated, the vibrations are transmitted through the bridge to the surface of the hollow body, and this also is caused to vibrate. It sets up sound waves in its interior and these pass to the outside air through the "f" or sound holes that are to be seen in the top face of the instrument. Without these sound holes a musical note would be obtained—due to the vibrating body transmitting vibrations direct to the outer air—but

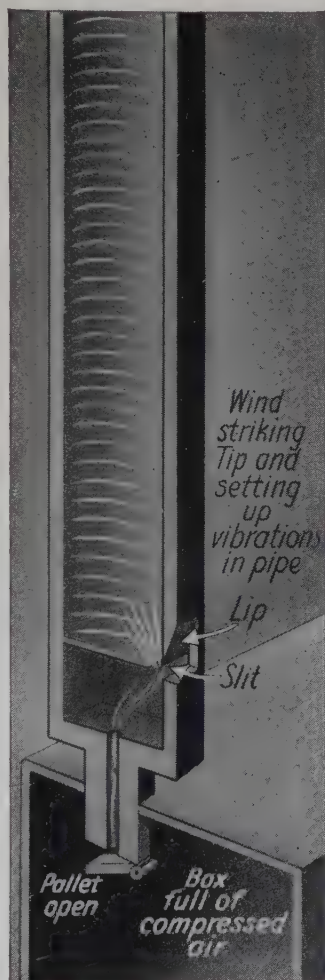


Fig. 5. How a pipe organ produces a note

the tone would be dull and without resonance or carrying power. The same principle applies to the harp, although in its case there is no bridge.

Instead, the vibration of the plucked strings is transmitted to the frame of the instrument, the lower portion of which is of hollow construction to give the necessary tone.

TENSION IN VIOLIN STRINGS

In stringed instruments the strings are set at different tensions in order to give the required variations in the number of vibrations per second. In the case of some stringed instruments the vibration of the string can readily be seen by drawing the bow heavily across the "open" strings—that is without the fingers pressing on them as when playing. In such a case the vibration is so rapid as to cause the string to appear blurred.

The vibration necessary to cover a wide range of pitch is very rapid. Middle C on a piano tuned to the

International Tempered Scale gives vibrations of 258.7 per second, but a satisfactory musical note would be heard on an instrument such as the organ, when the sound vibrations were only about 40 per second. The normal lowest note is that of a pipe organ 32 feet in length giving $16\frac{1}{2}$ a second. At the other end of the scale is the shrillest note in an orchestra—the highest note of the piccolo producing vibrations at the rate of 4,752 per second. The lowest note of some of our greatest bass singers gives a vibration of approximately 50 per second, while the highest note of the most famous Metropolitan soprano singers has been known to be as high as 1,500 per second.

Brass instruments, which is the term applied to the wind instruments of an orchestra not provided with reeds,

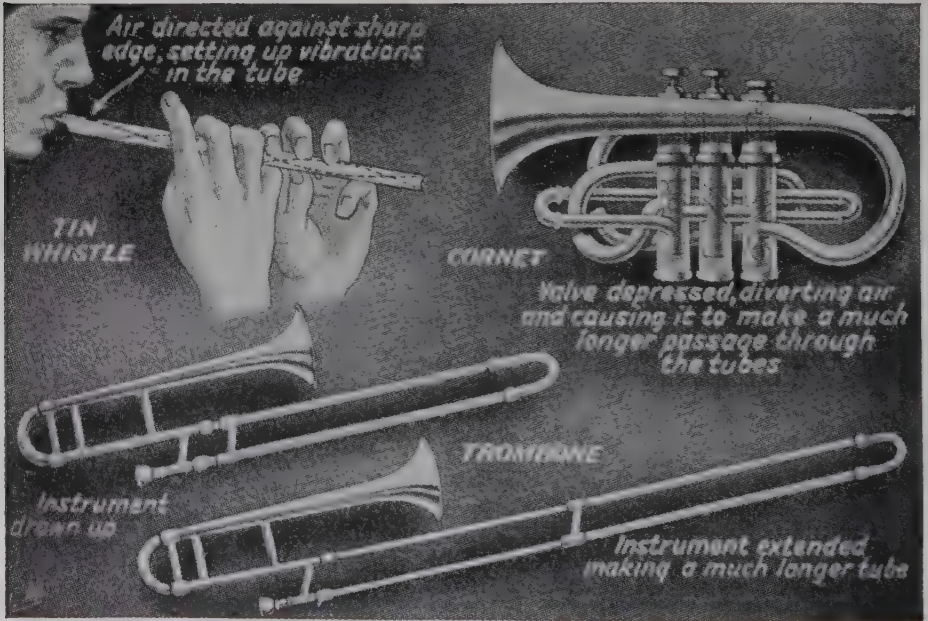


Fig. 6. How different notes are obtained from the cornet and trombone, basically pieces of metal tubing. The effective length of the tubing is varied as required, thus producing different notes

are simply lengths of metal tubing of varying diameters. Sound waves are set up by the instrumentalist forcing air through his lips at a certain velocity into a small hole in the mouthpiece (Fig. 6). For convenience in handling and playing, the tubing is coiled into various shapes, but the effect and principle is the same as if the instrument were made of a straight length of tubing. The simplest form of brass instrument is the old-fashioned post horn (Fig. 7), in which a series of notes is obtained merely by altering the velocity of air through the player's lips. The military bugle and trumpet are very similar, but here the tubing is coiled for convenience.

It will be noticed that with these instruments only a limited number of notes can be obtained, the range be-

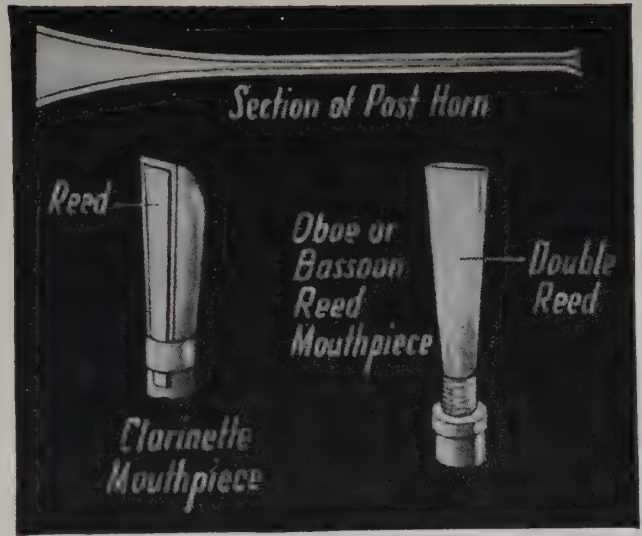


Fig. 7. (Top) The old-fashioned post horn is virtually a length of piping, the various notes being obtained by different adjustments of the player's lips. (Bottom) The notes of the clarinet and oboe are obtained by vibrating reeds

ing determined by the length of the tube. If other notes are required some artificial means of altering the tube length must be employed. The simplest way of doing this is that used in the slide trombone (Fig. 6). In this the player continues to blow with a velocity that normally would only pro-

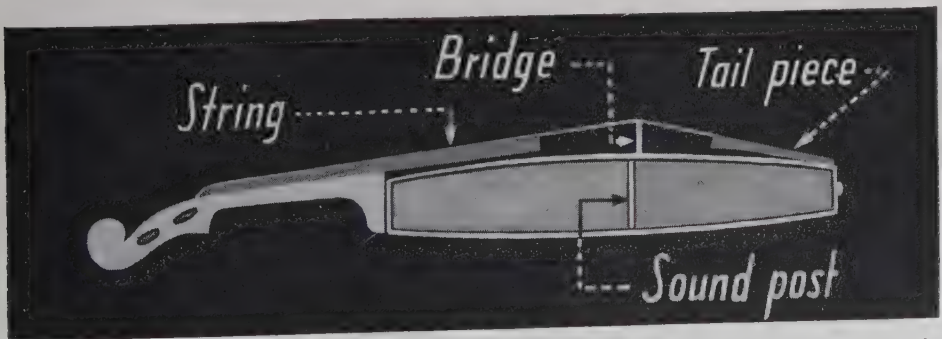


Fig. 8. In a violin the strings are stretched over a wooden bridge on the hollow body of the instrument, which is reinforced by a sound post to take the pressure from the stretched strings

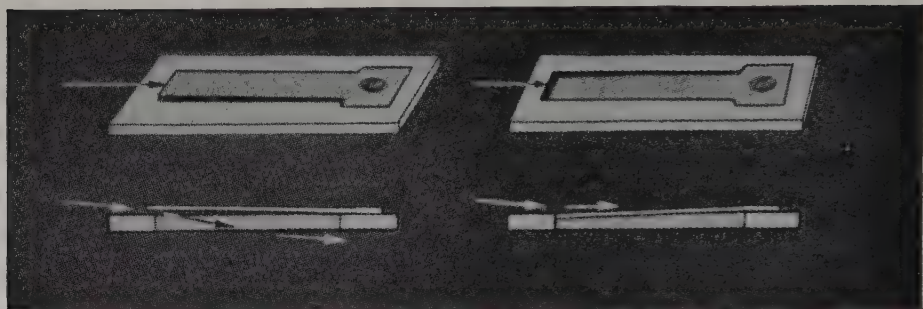


Fig. 9. How a reed is made to vibrate. The air current passes first under the reed (left) and then over it (right). In this way it is caused to vibrate very rapidly and thus to set up a musical note. In the clarinet and similar instruments the reed is in the form of a flat piece of cane

duce a certain note, but by moving the slide—thus lengthening or shortening the length of tubing—other notes may be obtained.

With other types of brass instruments—as in the cornet—a similar effect is obtained by operating valves that guide the air through small additional lengths of tubing. In yet other cases they shut off portions of the coils either to lengthen or shorten the effective length of tubing used (Fig. 6).

The descriptive adjective “wood-wind” is applied to those instruments in which a reed is used to produce vibrations. A reed is a thin strip of cane or metal vibrated by a current of air (Figs. 7 and 9). In the clarinet and similar instruments, the reed is in the form of a flat piece of cane that vibrates against an ebonite mouth-piece (Fig. 7). The effect is alternately to cut off and release with great rapidity the flow of air passed through the instrument by the player. By covering and uncovering various combinations of holes in these instruments the effect of a varying length of tubing is obtained, giving a wide range of musical notes.

USE OF THE DOUBLE REED

With instruments such as the oboe and bassoon, a double reed is used (Fig. 7). These reeds vibrate together to give the same effect on the air column, the note being weaker but of sweeter tone.

The flute, which is also classed as a wood-wind instrument, is similar in operation but here no reed is used: the player’s lips form the reed in conjunction with the edge of the hole over which the air is forced.

All instruments that are operated by striking with a hammer or stick are termed “percussion” instruments. The piano and similar instruments are exceptions to this rule, being classed with the strings. The comparatively unmusical note given out by the drums, cymbals, etc., is due to the complex vibrations given off, causing a certain distortion of the sound waves. The tympanum, which is a form of drum constructed on a large copper bowl, is capable of being tuned to a definite note, however, and large orchestras use several of various sizes. Tuning is done by tightening or loosening the skin to raise or lower

the pitch, so as to harmonize with the other instruments.

No matter by what means these vibrations may be caused, the sensation we call "hearing a sound" is due to vibrations in the air falling on the eardrum. From the drum the vibrations are conveyed to the auricular nerves in the interior parts of the ear by a wonderfully delicate series of linked bones known as the hammer, anvil, and stirrup. In reproducing sounds mechanically an artificial imitation of this mechanism of the human ear is used—the diaphragm of the telephone receiver, for instance, corresponds to the tympanum.

WHAT IS SOUND

Without ears to hear there would be no sound, for all nature is silent, just as, without eyes to see, all nature is in darkness. Sound is thus a silent wave motion that is interpreted into a sensation in the brain of the hearer. Exactly which part of the ear is the true organ of hearing is as yet a mystery, there being three current theories to account for the transmission of sound to the auditory nerve.

Sound waves spreading outwards from the source producing them differ in one important way from the wave produced by throwing a stone into a pond. In the latter case the wave travels in the water only, and more

especially along its surface, and therefore may be said to be a transverse wave on a plane surface. On the other hand, sound waves have a longitudinal direction of vibration—that is to say, the direction of vibration of the air particles is along the direction of travel of the wave. The progression of sound waves differs considerably from the sinuous lines that would depict the movement of a wave in water. Their movement must be regarded rather as a series of rapid pulsations of particles of air taking place in the direction in which the sound is propagated. Their only resemblance to waves on water is that they, too, present periodical phases in uniform succession.

An appropriate illustration of the transmission of a sound wave may be obtained by imagining a number of balls hanging from separate strings, the ball at the end hanging near to a bell as shown in Fig. 10. If the ball at the other end is drawn back and released so that it hits the second ball, the ball nearest the bell will suddenly strike the bell, causing it to ring. The balls in the row, which are all touching, do not appear to have been moved, but actually each one has been knocked forward, and each has rebounded, due to the impact of the first ball. Actual motion has been stopped in the individual balls by the

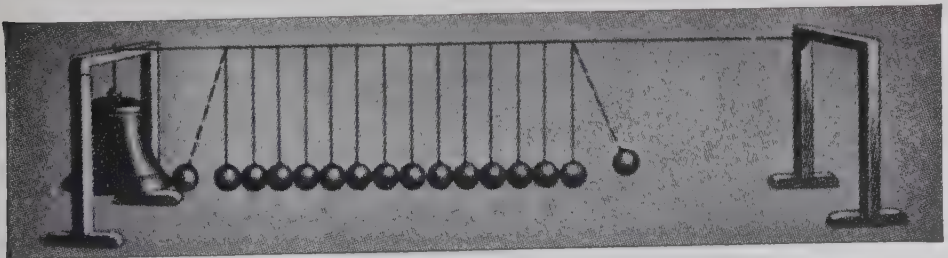


Fig. 10. Illustrating the way a sound wave is propagated by vibration. Principle involved is explained on this page

one in front of each, but as the last ball hangs freely, the impulse of the others is translated into motion and the bell rings.

It is in a way similar to this that the molecules of the air transmit series of compressions and rarefactions so that the impulse advances as a sound wave. When a force strikes the particles of the air, these particles are moved to and fro like a pendulum. The particles that are given the original impetus strike their neighbors, and they in turn pass on the vibrations to the next particles and so on, so that a wave of sound is created and travels on until the movement dies out.

HOW SOUND TRAVELS

It is important for us to understand clearly that this advancing of the sound wave is a wave motion only in the particles that compose it—the *particles themselves do not move forward*. This may be illustrated by throwing a stone into a pond, where a series of concentric waves will be seen to move from the spot where the stone entered the water. If a cork is thrown into the water in the path

of these waves it will be seen to rise and fall, but it is not carried along by the waves. This is because the waves are due to the oscillation of the individual molecules of water, the movement being communicated to each molecule in turn, as in the case of the hanging balls. Similarly, a sound wave is an impulse that travels through the air; it is not the translation of a body of air from one place to another.

A striking little experiment will illustrate more clearly that a sound wave is a form of energy and not an actual movement of particles. Place two pennies on the table, so that they are exactly touching. Hold down one firmly and lightly tap it with a third. The first penny will then be shot forward an appreciable distance, although the center penny has not moved a fraction of an inch. The energy imparted by the blow has been transmitted through the stationary penny, as in the experiment with the balls and the bell (Fig. 10). Some people, seeing this experiment, cannot believe their eyes and insist that there is a trick and that the center penny has been moved, but it may be

fastened to the table with a clamp if necessary to convince unbelievers (Fig. 11). Even the artist who drew this picture could not accept the experiment, so he clamped one penny to the table and still the experiment worked.

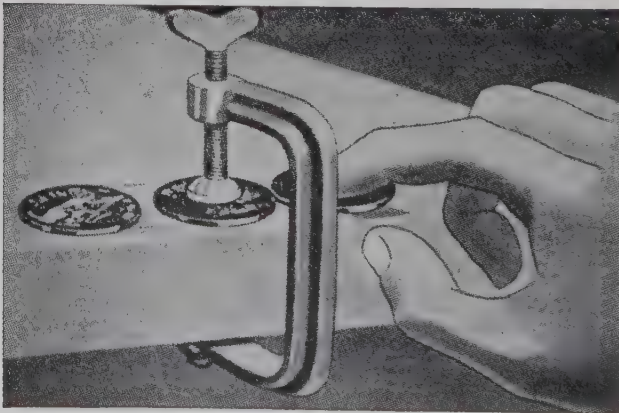


Fig. 11. An experiment with three pennies (see text)

NATURE OF SOUND WAVES

Some people think that it is curious that

all kinds of sounds—such as shrill whistles and deep bass notes—should travel at the same speed, but such is the fact. If two or more tuning forks are vibrated at the same time, the vibrations from each are transmitted independently and simultaneously, as if those from the other did not exist. They resemble the two sets of waves that travel over the surface of a pond, if two stones are thrown into it at the same instant.

It is a fortunate arrangement that two or more sound waves pass each other without interference, for, as a result, it is possible to transmit any number of sounds simultaneously without confusion. Otherwise, when listening to an orchestra at a distance we should be able to hear the general musical effect only when quite close to it, for sounds from the shrill piccolo and the drum would arrive at different instants; as it is, we know they all arrive in perfect time and combine to give harmony. The reason for this is that the velocity of propagation of all these waves is the same, whatever may be their frequency, or their amplitude. In short, the high and the low notes, the loud and the soft notes, all travel with the same velocity. No matter how many sounds are being transmitted over a given air space, an additional sound can always be transmitted exactly as though the air were still and undisturbed.

Let us see now how sound waves are propagated. Clearly to understand this we cannot do better than consider the action of the tuning fork, the prongs of which beat the air in opposite directions simultaneously. As a prong strikes the air the latter is driven away and compressed. As the compressed air travels outwards the prong recedes, and the air expands.

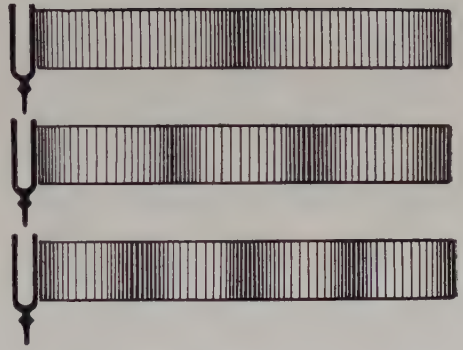


Fig. 12. Three tuning forks vibrating at different rates, thus giving different notes

Thus waves of condensation and rarefaction travel one behind the other at the same rate, maintaining the same relative positions with each wave traveling on with equal speed. Fig. 12 shows columns of air that are transmitting such vibrations from three tuning forks; the swiftly moving prongs of these tuning forks compress the air in front of them and, in swinging back, leave a vacuum behind by which the air is partly rarefied. These alternate waves of compression and rarefaction travel through the air and produce vibrations in the ear.

Tuning forks give different notes, according to their design. This means, simply, that they vibrate at different periods, so causing fewer or more waves of condensation and rarefaction per second. This will be more clearly understood by referring to Fig. 12, which shows three tuning forks tuned to three different notes.

Supposing a tuning fork to make 100 vibrations a second: at the end of the first second, the first wave will have traveled 1,100 feet—since this is the rate of travel for sound—and between this point and the tuning fork, there will be 100 sound waves, each 11 feet in length. As sound waves, no

matter what their length, all travel at the same speed through the same medium, it follows that the more rapid the vibrations the shorter is the wave length. If the vibrations are 1,100 a second, there will be 1,100 waves, each 1 foot in length; if 13,200 a second, the waves will be 1 inch in length, and so on.

This can be demonstrated if an electric bell be placed in a bell jar and the air gradually withdrawn. The sound will grow fainter and fainter as the air becomes more rarefied, and finally when a vacuum has been obtained no sound will be heard, although the hammer inside may still be clearly seen banging the bell.



Fig. 13. A siren consists of two discs, each perforated with a number of tiny holes, the top one being free to revolve; the holes are angular so that steam under pressure rotates the disc, alternately shutting off and releasing the steam. This sets up powerful vibrations

Sound travels more quickly in some mediums than in others. This is because the distances between the particles vary in different substances. Where the particles are close together there is but little loss of time in the transmission of energy from one particle to another. The particles of a liquid are closer together than those of a gas, so sound travels more easily in a liquid than in a gas, and, for the same reason, more easily in a solid than in a liquid. The velocity of sound in water is 4,900 feet per second, or more than four times its velocity in air.

NO SOUND IN A VACUUM

Newton showed that the extent of the capacity to propagate sound depends on the elasticity of the medium. In everyday life the elastic body that conducts sounds to our ears is the air. If this is taken away, or if there is any change in its composition, sounds previously audible become inaudible or indistinct. Thus it follows that sound cannot move through a vacuum.

GOOD CONDUCTORS OF SOUND

That sound can travel through solid substances may be demonstrated by laying a watch at the end of a wooden table and pressing the ear to the other end. The ticking of the watch will be heard distinctly even though it cannot be heard directly through the air, for sound travels better through 10 feet of wood than through 1 foot of air. Even the earth transmits sound more effi-

ciently than does the air. We all remember reading of Indians detecting the approach of their enemies, or of a herd of buffalo, by putting their ears close to the ground and listening.

That sound travels faster through some substances than others can be proved if we place an ear against a telegraph post and get a friend to hit the next post a sharp blow with a stick. In this case we hear two distinct sounds—first that through the wires and the post, and then an instant later the normal sound of the blow transmitted through the air. The reason for the two separate sounds is because of the different velocities of sound in solids and in gases—in this case the air. A similar and more striking test can be made if there is available a long unbroken stretch of iron railing. We get a friend with a hammer to strike the railing a sharp blow a couple of hundred yards away. If we put an ear to the railing two sounds will be heard—one through the railing itself and the other, an instant later, through the air.

Sound travels through granite at 1,664 feet per second; through lead at 4,030 feet per second; through pinewood at 11,000 feet per second. Its velocity through iron is 17,500 feet per second, or about fifteen times as fast as through air. Steel is obviously more difficult to compress than air—actually it is over a million times less compressible and it is over 6,000 times as dense. Because of this, sound travels at three miles a second in steel.

Sound spreads in every direction—upwards, sideways, forwards, and backwards; with the result that the amount of sound received by a lis-

tener placed 50 feet from its source is only about one fifty-millionth part of the total sound emitted. At twice the distance, that is 100 feet, the wave is spread over four times the area, and only a quarter of the amount mentioned in the first case is received by a listener. Thus we see that with every increase in the distance of the hearer from the source of sound, the amount of energy diminishes enormously. This is expressed more scientifically by saying that the intensity of a sound varies inversely as the square of its distance.

EFFECTS OF LOW TEMPERATURE

When considering the intensity of sound we have also to take into consideration the density of the medium through which the waves are transmitted. On a frosty night sounds are heard more clearly and over a greater distance because the air is denser. On the other hand, a revolver fired on a high mountain, where the air is less dense, gives a report that may be no louder than that of a cap pistol fired at sea level.

Everyone has noticed circumstances indicating that sound takes an appreciable time to travel over any distance. If the firing of a gun is watched from a distance, the moment of firing will be signalized by the flash from the muzzle. The sound of the explosion will be heard a little while afterwards, however. During a thunderstorm the noise we call thunder, which is actually the noise of the electrical discharge known as lightning, is heard some time after the lightning flash has been seen. As light travels almost instantaneously it is always observed before the sound that accompanies it.

This delay in the sound wave reaching the ear gives a rough guide as to the distance of the source of the sound.

SPEED OF SOUND

The speed at which sound travels is affected by the temperature and actual constitution of the atmosphere. The former affects the atmosphere's compressibility, and the latter—by the amount of water vapor it contains—its density. This is because air is an elastic medium, and the greater the elasticity, the more quickly will the molecules tend to return to their original condition after the passage of the wave. Consequently, the velocity of the transmitted wave will be greater. An alteration of $1^{\circ}\text{C}.$ in the temperature will affect the velocity of a sound wave by 2 feet per second. At a temperature of $1^{\circ}\text{C}.$ sound travels at about 1,087 feet per second, so that at $20^{\circ}\text{C}.$ the velocity will be increased to 1,127 feet per second. As an average velocity at normal temperature we can take a figure of 1,100 feet a second, or 750 miles an hour. We can prove this roughly ourselves by watching blasting operations, or a gun being fired at, say, a distance of five miles. The sound of the explosion will not reach our ears until about 25 seconds after we have seen the flash.

The knowledge of the velocity of sound is used in warfare to determine the position of hidden enemy guns. In one method of "sound-ranging," as it is called, three microphones are used, placed, say, half a mile apart (Fig. 14). In the diagram is shown an aerial view of an area in which the opposing armies are operating. The inset A, top left, is a

map of the same area. When the enemy gun, hidden in the trees in the bottom left corner, was fired, the sound vibration passed the microphones and the resulting currents were registered at a central observing station (B, Fig. 14) by actuating delicate galvanometers. From the needle of each of these a spot of light was reflected on to a piece of sensitized film mounted on a rotating drum. Time signals were also recorded on the film alongside the light-trace from the galvanometer. Owing to their varying distances from the source of the sound, the microphones recorded the passing of the sound wave at slightly different times (C, Fig. 14). By comparing the differences in these times the position of the enemy gun could be ascertained, and when this had been done the information was communicated to the artillery for the "necessary attention and action."

FREQUENCY OR PITCH

As sound waves are a periodic phenomenon, they are subject to the ordinary laws of harmonic motion, by which one sound wave may differ from another, and therefore one musical note from another, in certain essential properties. The frequency, or "pitch," of the waves of compression and rarefaction, alternately pressing inward and releasing the tympanum, determines the note received by the ear. Frequency depends on the number of impulses in a given fraction of time, and, for convenience, frequency is referred to in terms of "cycles per second," or "c.p.s."

LIMITATIONS OF AUDIBILITY

As the frequency increases, the waves become shorter, and the pitch

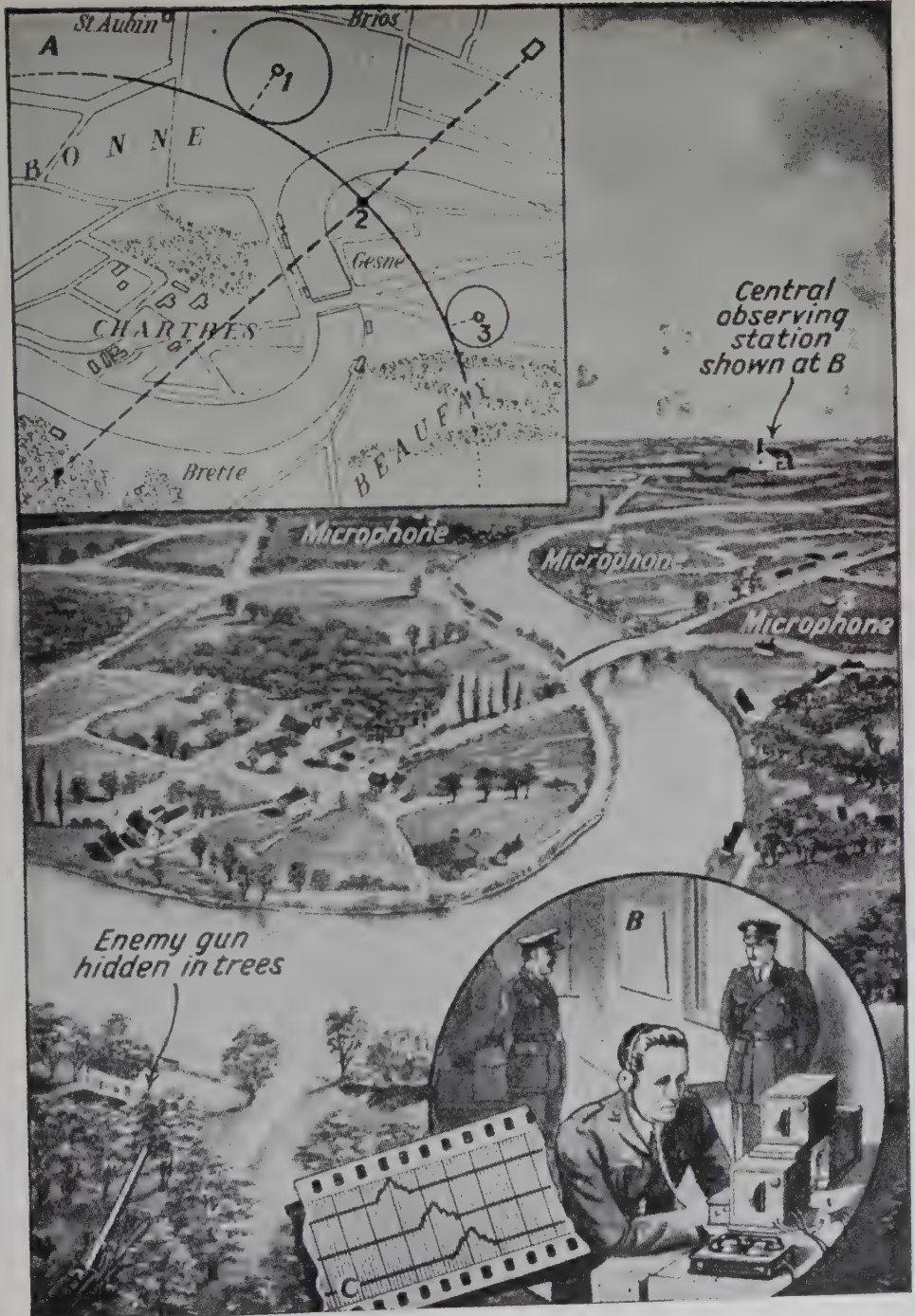


Fig. 14. How the exact position of an enemy gun may be calculated from sound waves

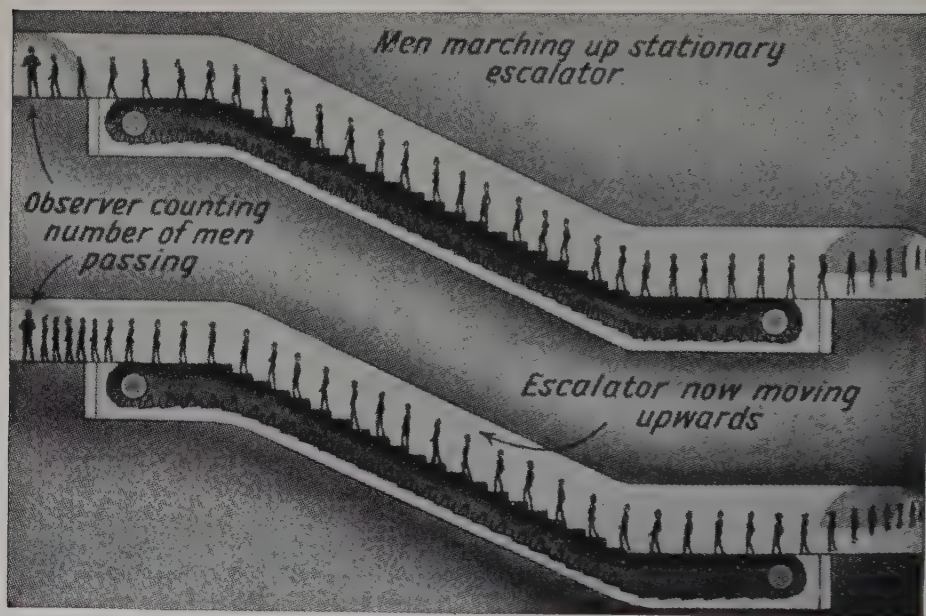


Fig. 15. Illustrating how pitch and speed of sound interact (see text). Fewer people appear to pass the observer at the top of a stationary escalator than at the top of a moving one

rises, until it may ultimately become so high that it is inaudible to the human ear. Exactly as the eye has its limitations as to what wave lengths of light it can perceive, so has the human ear its limitations of sounds that are audible. When a toy musical top is set spinning at a very high speed, no "music" is heard, but as the speed drops we hear first a very high note, the pitch of which drops as the speed of the top decreases. Finally, a very low note is produced, and although this apparently ceases, vibrations continue to be produced, though of too low a "pitch" to be detected as a sound. In sound the audible limitations differ slightly with different people. Generally speaking, the lowest frequency audible is about 16, and the highest about 30,000 or 40,000 cycles per second. Some people can hear sounds of higher frequency than

others—some are able to hear a canary singing very high notes when to others, whose ears are not so responsive to these very high frequencies, the bird seems to be silent. Sounds that are often beyond the range of many people's ears include the squeak of the bat and the chirps of the cricket. Sounds that are inaudible to the human ear, but are easily audible to a dog or a horse, can be produced by Galton's whistle, in which the note is varied by the movement of a plunger, as in the trombone.

The lowest note heard by the average person is caused by waves 65 feet in length with a frequency of 16 cycles per second. The highest are caused by waves $\frac{1}{3}$ inch in length with a frequency of 38,000 per second. On a piano the range of notes represents vibrations of from about 30 to 8,000 per second.

So beautifully is the mechanism of the ear adjusted that as minute a difference in frequency as 1 in 400 c.p.s. can be appreciated, but, curiously enough, only for those notes that are within the compass of the human voice. Within the range mentioned are the numerous tones we hear in a musical performance—the more rapid the frequency the more acute the tone or pitch. This may be seen, for example, by comparing the first and second graphs in Fig. 24. The former shows a record, as made on the Low-Hilger Audiometer (see page 300), of a violin *E*, frequency 689 c.p.s., and the latter of violin *D*, frequency 307 c.p.s.

SPEED AND PITCH

Almost everyone has noticed the peculiar sound effect experienced when standing on an open station platform as an express train dashes through emitting a whistle. As the train approaches us the pitch of the whistle steadily rises and after it has passed us and is receding, the pitch lowers. We have seen that the pitch of a note depends on the frequency with which the vibrations strike the ear. In the case of the express, the frequency is increased as the engine approaches because the sound waves have added to their normal speed of travel the speed of the engine; the rate of travel of which, in the

case of an express train, is about one-tenth the velocity of sound.

An illustration of what happens is afforded by a gun in action firing shells at a target at fixed intervals of time. If the gun is mounted on a moving platform that advances, say, 500 yards between the firing of each shell, it is obvious that the shells will fall more frequently on the target than if the gun were to remain stationary in its original position. Similarly, if the gun retires 500 yards between the firing of each shell, the shells will strike their objective at correspondingly greater intervals. Whether the gun or the target is in motion is immaterial, for the result will be the same in either case (Fig. 15). Here, in the top drawing, passengers are seen going up an escalator. Fewer men appear to pass the observer at

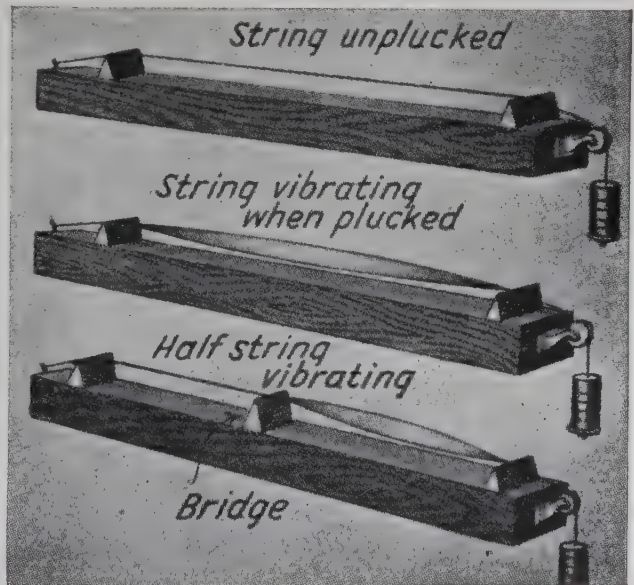


Fig. 16. Showing how a plucked string vibrates. By decreasing the length of a string, by the intervention of a bridge, as shown in the drawing, or by pressing on it with the fingers, as does the violinist, the pitch is altered

the top than when the escalator is moving.

Actually, therefore, in the case of the train, the pitch of the whistle will be the same to the engine driver and the bystander only at the moment when the train is passing the platform.

The phenomenon is particularly noticeable when a high-speed airplane is flying low and passes overhead. When the Thompson Trophy race was broadcast, for instance, the note of the machines, traveling low at over 300 miles an hour, showed a drop in pitch of nearly an octave. This principle was discovered, in 1842, by C. J. Doppler, an Austrian physicist.

STRINGED INSTRUMENTS

In a stringed instrument the pitch is altered either by decreasing the length of a string or by increasing its tautness, for a taut string vibrates more frequently and produces a higher note than a loose one (Fig. 16). A simple musical note is the result of a continuous, rapid, and uniformly recurring series of impulses. For example, the note A^1 on a piano has a frequency of 439, or in other words when this note is struck the sound waves reach the ear of the listener at 439 cycles per second. C^1 has a frequency of 522 c.p.s.; C^{11} 1044 c.p.s.

There are other characteristics of a musical note in addition to pitch. One of these is the quality, often called the *timbre* or "tone-color," by which we are able to distinguish between a note sounded on a violin and the same note sounded on a flute. H. von Helmholtz, the German scientist, showed that timbre is due to the number and intensity of the supplementary notes, called "overtones" and "harmonics," that are also given out by the string. These overtones are

present in all musical notes and give them their characteristic timbre.

Overtones arise because a string vibrates not only as a whole but in parts as well—in two parts giving vibrations from each half (A, Fig. 17); in three parts giving vibrations from half of two-thirds (B, Fig. 17); in four parts giving half of half, and so on. Thus, in addition to the original key-note, say C, we have the octave C (half) the G in the octave above (half of two-thirds) and the next C (half of half), and so on. We thus see that the number of vibrations is doubled by halving the original length of the string—actually, the vibrations vary inversely to the length of the string—as every violinist knows. As we have already mentioned, a similar effect is obtained by altering the degree of tension of a string, and this variation depends on the square root of the tension applied. Thus, to cause a string to vibrate twice as quickly the tension must be increased four times; to cause it to vibrate three times as quickly the tension must be increased nine times, and so on.

In addition to length and tension, the diameter of a string is another factor that affects the note it gives out. Given the same length of string and the same degree of tension, a string of double the diameter will give a note one octave lower, for it vibrates only half as quickly as a string half of its diameter. Two strings of similar lengths, tension, and diameter, but of denser material, will vibrate differently, the heavier one vibrating less rapidly than the other. A violin G-string is a gut string closely wrapped round with fine copper or silver wire, and because its density has thus been increased it emits a deeper note even than that of a thick gut string at the

same tension. The number of vibrations varies inversely to the diameter of the string and inversely to the square root of the density of the string.

Yet another characteristic of a musical note is its intensity—whether the sound is loud or soft—and this depends on the amplitude of the vibrations. Amplitude may be said to be the extent to which each particle in the line of transmission oscillates to and fro about its mean position of rest. For the least audible sound the extent of motion of the air particles is about one five-millionth of an inch on each side of their mean position. If the amplitude is increased, the sound becomes louder and can be heard at a greater distance—in other words, intensity is dependent on the extent of the vibrations. Notice in the lowest graph (violin G) in Fig. 24, how the amplitude decreases towards the right-hand side.

The knowledge of these several properties and characteristics of sound waves enables us to better understand the wonderful delicacy of the human ear. All these vibrations are interpreted, without conscious effort on our part, into pitch, timbre, and amplitude, by the marvelous mechanism of the tympanum and its connected parts.

REFLECTION OF SOUND

If the end of a rope is shaken, a wave travels along it as a “crest,” and when the wave reaches the other end of the rope it is reflected and returns as a “hollow.” In a similar manner,

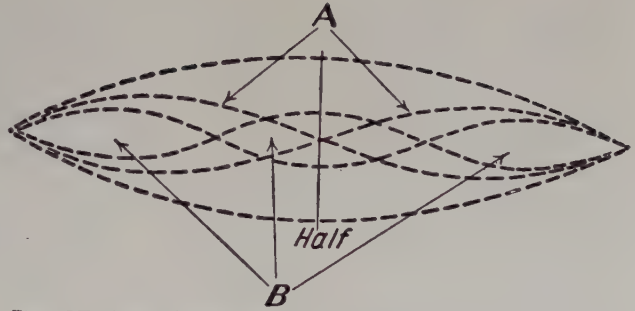


Fig. 17. How “overtones,” or supplementary vibrations of a string, arise

sound waves may be reflected, exactly as light waves are. When this occurs they are always reflected at the same angle as that at which they strike the surface—or to express it more scientifically, the angle of reflection is equal to the angle of incidence, a law that also applies to all other wave motions. Theoretically, this is what should happen when a billiard ball strikes the cushion of the table, and no doubt many billiard players often wish that practice was more often in accord with the theory than actually it is.

In the case of rays of light striking a mirror, we see “behind” it a reflected image of the objects that are really in front. When driving in a car we hear the sound it makes reflected from the fences and trees we pass, for sound does not necessarily require a flat unbroken surface for its reflection. Even isolated posts will throw back a “zip” of sound. A length of railings gives a quick succession of reflections almost like the ticking of a clock, or sometimes when the car is nearer to them the reflection resembles the sound of a machine gun in action.

Reflected sound is termed an *echo*, and the length of time required for

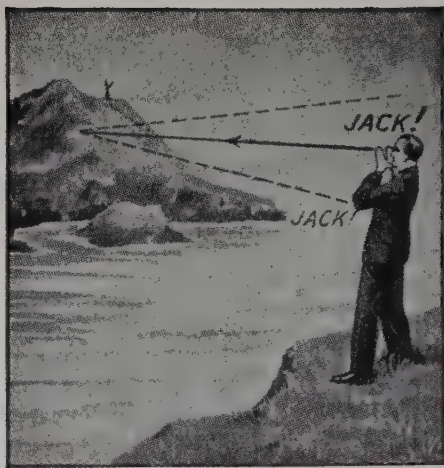


Fig. 18. An echo is merely sound waves turned back after they have struck a reflecting surface. It proves that sound takes time to travel

the sound to be reflected back to its source depends on the distance of the reflecting surface. The echo is another illustration of the fact that sound takes time to travel. The sound made by a person shouting has to travel some distance until it strikes a surface that has the property of reflecting back, or echoing, this sound. Then it has to travel back to our ears and an appreciable time is taken on each journey, resulting in our hearing the repetition of the original sound some little time after it originated (Fig. 18).

There is a curious phenomenon known as the *persistence of sound*, due to the sensation of sound persisting in our brain for about a tenth of a second after the sound waves cease to reach the eardrum. Thus, if the walls of a room are more than 50 feet away, a reflection of a voice can be heard as an echo. In a smaller room than this, however, the reflected waves blend with the original sound waves and reinforce them, so that a

voice will sound louder than in the larger room.

OVERCOMING ECHO

Echoes sometimes cause serious problems for architects, since they may interfere with the acoustic properties of churches and theaters, and of halls used for public speaking or musical performances. The problem that has to be overcome is to prevent echoes which cause blurring of the sound, because the time it takes to travel from the source to some reflecting surface and back to the listener's ear is longer than the time taken for sound waves to travel to the listener direct. Such a condition causes the echo of one note to be heard almost at the same time as the next note, traveling direct, strikes the ear. The result is a distorted sound that is musically unpleasant. To prevent echoes in buildings it is necessary to break up those sound waves that do not travel directly from the speaker to the audience. Sometimes this is done by stretching wires over the heads of the audience or by an arrangement of curtains or partitions. Even the design and the composition of the upholstery used on the seats in a hall have an appreciable effect on echoes.

CONCENTRATING SOUND

Obviously, a sound would travel to a greater distance if it could be prevented from spreading in all directions. If we take the 6-volt bulb out of the reflector of the headlight of a motorcar, we are surprised to notice what a comparatively feeble light it gives, as compared with the strong, dazzling beam when it is in position in the headlamp, when all the rays of light are conserved and made to travel in the same direction. The principle

of the echo may be employed in several ways by using a series of reflections, as in the case of the sound that is reflected from more than one surface in the famous "whispering gallery" in St. Paul's Cathedral, London (Fig. 19). This same principle of repeated reflection is used in the ear trumpet and in speaking tubes generally. We get a somewhat similar effect by the use of a megaphone, by which the voice can be carried to a greater distance than would otherwise be the case. We use the same principle in an automobile horn, a ship's siren, a stethoscope, and other similar devices.

The principle of the echo is also used to measure the depths of the sea by an interesting instrument called the "echometer." The importance of such an instrument can best be appreciated by considering the figures, published periodically, showing the causes of loss of ships at sea. These figures show that even during the past few years, when numerous scientific aids to navigation have been made

available, more than 50 per cent of the losses have been due to stranding and kindred causes. This is a clear indication of the necessity for apparatus that will show the navigator the depth of water under his ship.

There are several types of echometers, but we take the Marconi device as representative of them all. Irrespective of the speed of the vessel or weather conditions, and no matter how quickly the ocean bed may vary, this device gives an immediate record of all depths between 2 and 360 fathoms under the keel of the ship. It is a separate unit, capable of being operated from a small battery, and is silent in operation. With this device the nature of the sea bottom—i.e. whether hard or soft—can also be ascertained. The instrument relies for its efficiency on supersonic waves (that is, waves that are of a higher frequency than can be detected by the human ear) that are concentrated into a beam. The navigating officer is able to discover the depth without having to take soundings by the old

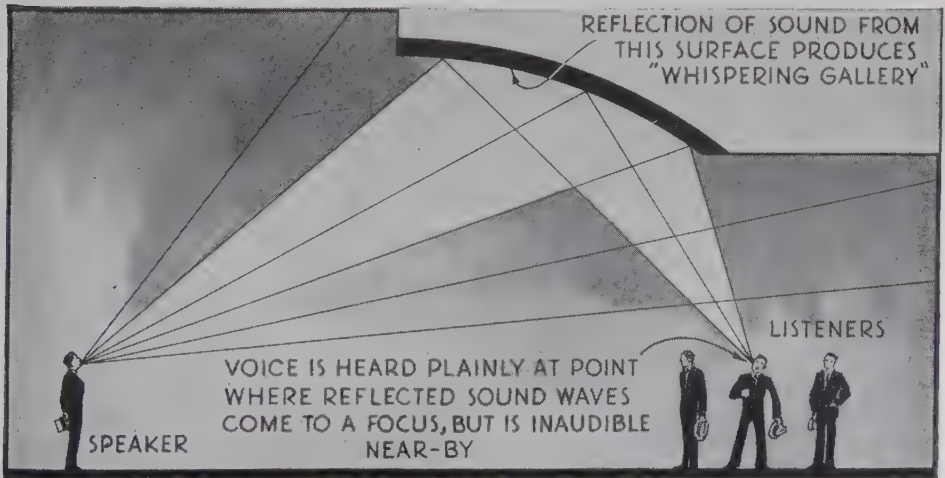


Fig. 19. Diagrammatic explanation of the "Whispering Gallery." See text on this page for full details

laborious method. Before the automatic echo-sounding device was introduced there was always a certain reluctance to take soundings frequently, particularly in rough weather when the men taking the soundings were exposed to the fury of the elements. Further, the old method involved considerable loss of time, since it was often necessary to slow down or stop the ship while soundings were being taken.

THE ECHO-SOUNDING DEVICE

Briefly, the echometer consists of a projector housed in the bottom of the ship. When a "transmission" is to be made an oscillating current is applied for an instant across two thick steel plates. This current causes the outer plate to vibrate at high frequency, imparting a wave motion to the water. The signal traveling to the bottom of the sea is reflected back again and strikes the projector. A reverse process then takes place and a small voltage is set up in the circuit connected to the projector. The measurement of the depth of water is thus a question of measuring the interval of time between the transmission and the reception of the echo; a task that is automatically carried out by the instrument itself, the result being recorded on a moving strip of paper (Fig. 20).

Exactly as sound may be reflected, so, too, can it be refracted or bent, when passed from one medium to another of different density. If a piano is being played in a room, the sound is transmitted by the air to the wall, through which it passes to continue its way through the air of the next room. The direction of travel of the sound waves in the second room is different from their direction in the first room,

for they have been refracted when passing through the intervening wall.

Sound waves may be brought to a focus, as light waves are, by refraction. This has been shown in an experiment originally performed by Lord Rayleigh. He filled a balloon with carbon dioxide and placed a watch on one side of it. The sound of the ticking was brought to a focus at a definite point on the other side of the balloon (Fig. 21). In the experiment the gas in the balloon corresponds to a telescope lens, refracting the sound waves in a manner similar to that in which the lens refracts the light from a star, bringing the rays to a focus at the eyepiece end.

WORLD'S LOUDEST SOUND

The world's loudest sound was caused (August 27, 1883) by the eruption of Krakatoa, already mentioned in an earlier section of this book. The sound of the explosion, by which two-thirds of the island was torn away, was heard over nearly one-eighth of the earth's surface. Preliminary sounds, resembling the discharge of artillery, were heard on the coast of Borneo, and even farther away. In Achin, in the extreme north of Sumatra and 1,073 miles distant, the people thought that an invasion was being attempted, and troops were put under arms to repel the supposed attack! At Singapore, 522 miles away, two steamers were despatched to sea, it being thought that some vessel was firing guns as a signal of distress. The noise was heard in places 3,000 miles from the scene of the explosion. To the north of Krakatoa, it was heard at Bangkok, in Siam; to the south, in South Australia. To the west, the sounds reached far beyond Ceylon, to the Chagos Islands in the Indian

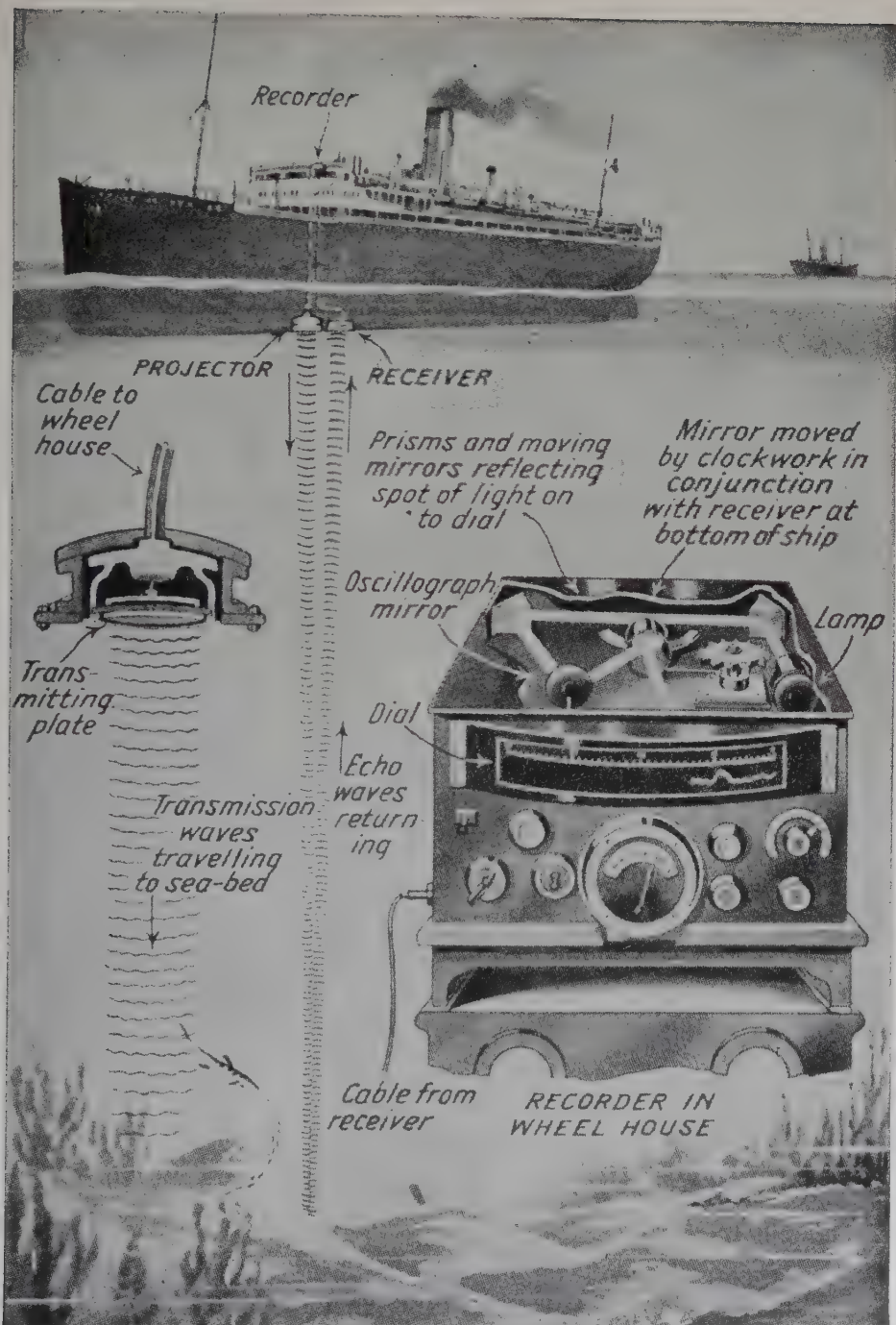


Fig. 20. The echometer by which the sea depths are determined

Ocean. They arrived at Rodriguez about four hours after the explosion had taken place. We shall perhaps more readily appreciate the magnitude of the distances covered by the sound if we imagine the explosion had taken place in the northern hemisphere. Had Krakatoa been situated in the Canary Islands the sounds would have been heard in the United States and in Britain. Had it been at the North Pole it might have been heard in France and on the shore of the Caspian Sea.

The whole atmosphere of the earth trembled from the resulting air waves that completely encircled the globe, moving outward in an ever-widening circle until they were 90° from Krakatoa. Thereafter, they continued to advance, but now contracting to a point at the opposite side of the earth to Krakatoa. From here the wave returned once again to Krakatoa and, having reached its place of origin, traveled again to the opposite side. This performance was repeated at least seven times, each time with diminishing force.

A rather unexpected characteristic of sound is that in some circumstances

it can actually be felt. If we stand near a gun when it is fired, a disturbance of the air will be felt at the moment we hear the sound. In the case of a large explosion the disturbance is sufficiently great to cause damage, such as broken windows, etc. Another striking example of this is the effect of playing very low notes on an organ. No doubt we have all been in a church or a concert hall where these low notes have been played, and have felt a throbbing of the air and in some cases of the actual building. Although no such disturbances are felt with the majority of sounds, they are nevertheless present and would be felt if our senses were sufficiently developed to detect them.

SOUNDS MAKE SHAPES

Such disturbances can be recorded, however, and in fact it is they that make possible the phonograph and the talking motion picture, the sounds being recorded on "records," and on film respectively—the greatest advance for the modern amusement world.

One of the simplest ways of producing a record of sound is by drawing a vibrating tuning fork over a sheet of

paper so that a piece of lead from a pencil attached to one prong will leave behind it a wavy line, as shown in Fig. 23. This is only a crude arrangement in which the prong soon comes to rest, its energy being overcome by friction. A more satisfactory arrangement, suggested by Duhamel in the early days of sound recording, is that in which

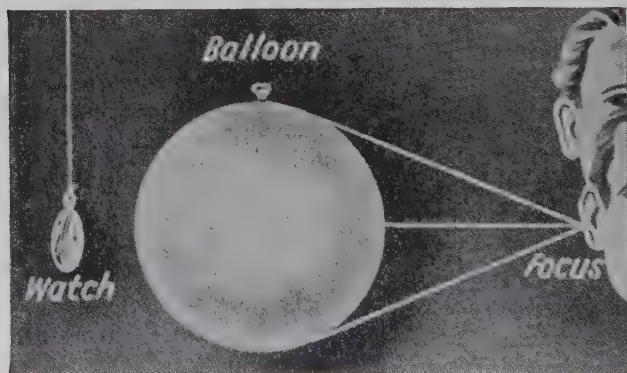


Fig. 21. How sound waves may be brought to a focus by means of a simple gas-filled rubber balloon

the friction is reduced by using smoked paper mounted on a revolving drum, the piece of lead being replaced by a stout bristle (Fig. 22).

In 1856, many years before the invention of a machine that would record and reproduce sounds, Leon Scott invented an instrument by which the vibrations produced by speech could be recorded graphically on paper. This device, called the phonautograph, consisted of a conical metal trumpet or horn, across the smaller end of which was stretched a membrane. To this was attached a light stylus that left a record of the vibrations of the membrane on a blackened cylinder rotated by hand. When any sound was produced near the open end of the horn, the impulses reflected from its internal surface were concentrated on the membrane, throwing it into corresponding vibrations and recording the sound on the prepared paper.

MODERN RECORDING

Sound waves today are recorded on a similar principle but by much improved apparatus. In the Low-Hilger Audiometer the pressure-variations of sound waves are recorded as they im-

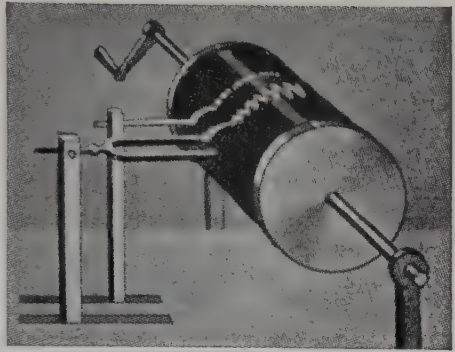


Fig. 22. Another method of recording sound vibrations. A bristle attached to a tuning fork will mark a piece of smoked paper, mounted on a hand-operated revolving drum

pinge upon an extremely light diaphragm of celluloid, rubber, or other material—the material used depending upon the degree of sensitivity required. This diaphragm carries a tiny mirror, and a beam of light from a lamp falling on it is deflected to a photographic film mounted on a shallow revolving drum (Fig. 24).

This is enclosed in a specially designed camera box, provided with an automatic shutter arranged to expose such parts of the film as may be required. Records such as are made by

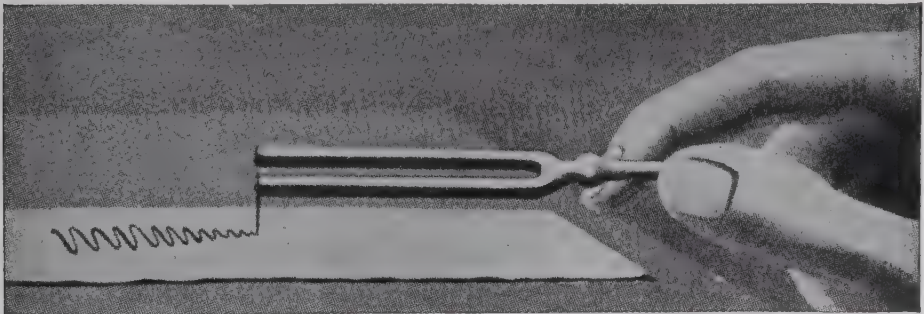


Fig. 23. A simple, but elementary, way of making a record of sound vibrations by attaching a piece of black lead to a tuning fork. An advance on this method is shown in Fig. 22

this apparatus are depicted in the inset.

As we have already seen, the records appear as long wavy lines, made up of what may be termed "hills and valleys." The height of the hills and the depth of the valleys indicate the amplitude and this varies according to the intensity of the disturbance that causes the wave. The number of hills and valleys in a given space on the record gives the frequency, on which the pitch of the note depends.

The human voice, the strings of a piano, the reeds of wind instruments, and all other sounds have characteristic records. Indeed, it would not be difficult for a student of sound waves to state the origin of any sound record merely by studying the trace produced. The overtones appear as additional and more rapid vibrations, forming secondary frequencies in

every complete wave cycle, and may be likened to the independent ripples that travel over the surface of the larger waves in the ocean.

Leon Scott, whose work we have mentioned, did not suggest that the sounds giving rise to the traces in his recording instrument could be reproduced. Obviously, however, if there could be a reversal of the process so that the record on the paper could be made to actuate the stylus and the membrane, they would throw the air within the horn into corresponding vibrations. A few years after the invention of the phonautograph, however, a M. Cross deposited at the Academy of Sciences in Paris a sealed paper. This was opened after Edison had patented the phonograph in 1877, and was found to contain suggestions of how the sounds recorded by the phonautograph might be reproduced.

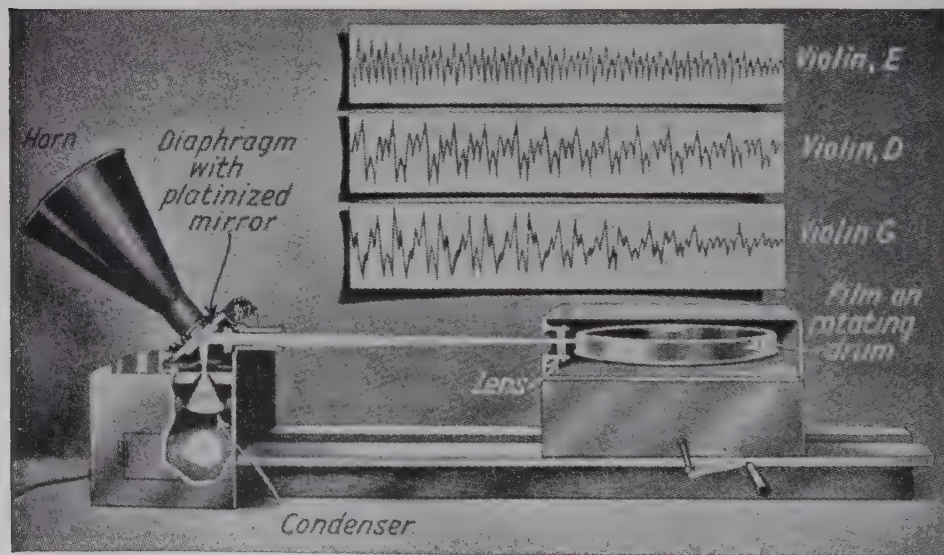


Fig. 24. The Low-Hilger Audiometer which is used for recording sounds. The method is explained in the text. (Insert) Three records made from violin notes, showing clearly the different frequencies and decreasing amplitude of the sounds made by the three violins

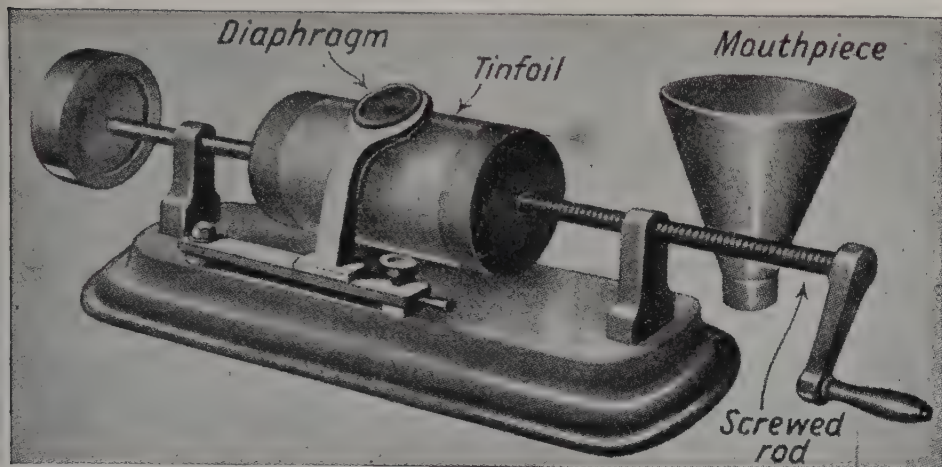


Fig. 25. Edison's "talking phonograph," ancestor of the present-day instrument

ORIGINS OF THE PHONOGRAPH

Edison's attention was drawn to the possibility of inventing a "talking machine" when he was working on high-speed automatic telegraph instruments. In this connection, when experimenting with embossed strips, he noticed that if these strips were moved rapidly beneath a metal pen so as to vibrate it, the pen produced a peculiar sound. This led him to the idea that undulations could be made on the strips and arranged in regular form so as to cause a diaphragm to vibrate and so produce certain sounds. From this beginning he was led on to the idea that the undulations might be produced by the sounds themselves, and he started to experiment on these lines.

Edison's efforts resulted in the production of the "talking phonograph" (Fig. 25). This consisted of a mounted diaphragm so arranged as to operate a small steel stylus, bearing on a solid brass cylinder about 6 inches in length and 4 inches in diameter. The diaphragm was supported by an adjustable bracket, and carried the steel

stylus on a small flat steel spring, there being a piece of India rubber between the two to modify the action. A spiral groove was cut in the circumference of the cylinder from one end to the other, and a corresponding thread was cut in the shaft on which it was mounted. When the shaft was turned by a hand crank the cylinder revolved and receiving a forward or backward movement along the shaft, the stylus was able to describe a spiral circuit around the surface of the cylinder.

The first records were made with the stylus lightly pressing on tinfoil wrapped around the cylinder, the crank being turned so as to bring fresh tinfoil beneath the stylus. Sounds made in the mouthpiece caused the diaphragm to vibrate, the stylus marking the soft tinfoil with indentations of different depths, corresponding to the amplitude of the vibrations of the diaphragm.

EDISON'S FIRST PHONOGRAPH

When the recording was done and the tinfoil covered, the cylinder was

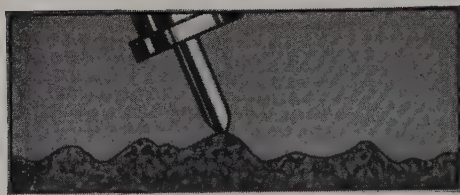


Fig. 26a. Needle in contact with record made on the early "hill-and-valley" principle of sound recording

wound back to the starting point, and the record was then "played." The diaphragm clearly repeated all that had been spoken into the mouthpiece when the record was made. Into the trumpet of his first experimental model Edison spoke the rhyme "Mary had a little lamb," and when the cylinder was turned back, the words were heard like a faint echo. He applied for a patent on Christmas Eve, 1877, but was too busy to further develop the invention at that time.

Alexander Graham Bell, the inventor of the telephone, his brother, Dr. Chichester Bell, and an assistant, Charles S. Tainter, undertook to improve it. After long experiment they found that paraffin wax, with a small admixture of some other substances, was a better material than tinfoil for recording the impressions. A cutting stylus bearing on this wax cut out a fine groove that gave a perfect record of every degree of inflection of a speaker's voice. The new form of the instrument was called the graphophone, to distinguish it from Edison's phonograph. In it the cylinder did not move forward as in the phonograph, but instead the diaphragm was made to move parallel to the revolving cylinder. The cylinder was driven by a treadle, like a sewing machine, and there was an ingenious arrangement by which the

speed could be controlled and kept uniform.

Edison later returned to the subject, and using solid wax cylinders with a perfectly uniform surface, obtained a great increase in the clarity of speech and tonality of music. These later instruments were driven by small electric motors, and the speed was regulated by a centrifugal governor. The wax cylinders were capable of being replayed a thousand times or more without deterioration. Writing of the usefulness of the phonograph not many decades ago, an author claimed that the new invention would enable "the songs of a fine singer in all their modulations to reach people in distant lands, or be audible to future generations. Thousands of people the world over have heard with their ears, through Mr. Edison's instruments, songs and speeches and pieces of concert music, sung, said, or played in America months before. Music can be bottled up, so to speak, without the consent of the originators. A speech of Mr. Gladstone's delivered in England, has been phonographically heard in New York with great applause." How surprised the writer of those words would be if he could see the modern electric record-changing phonograph built in a modern radio!

While Edison and Bell were perfecting their phonographs and graphophones, Emile Berliner, an American of German extraction, revolutionized the system on which they were working. He had already greatly improved the telephone, over which Edison and Bell had long been fighting, and in 1887, by inventing the gramophone, he again stepped in and snatched from them the prize for which they were struggling. Not only did Ber-

liner's gramophone use flat discs, which are more convenient in shape than cylindrical records, but its movements were more simple. It required only a single movement to spin the turntable, whereas in the phonograph two movements were necessary—one to rotate the cylinder and the other to move the reproducer along the spiral groove on the cylinder. Further, Berliner's gramophone was free from a fault common to both the Edison and the Bell systems. Edison and Bell were using a method of recording sound, whereby the indentations of the cutting stylus were impressed on the floor of a groove in the record. If we could see a magnified section of such a sound track we should notice that the track resembled a succession of hills and valleys, caused by the varying impressions of the stylus on the wax (Fig. 26a).

BERLINER'S IMPROVEMENT

Berliner saw that this early method was unsound, for the reproducing needle would jump from the top of one "hill" to the next and completely skip over the "valley"; not only were sound vibrations missed but a good deal of unnecessary noise was produced as well. Berliner set to work in 1887 and produced something quite different from the "hill-and-valley" cut. In his device the depth of the grooves in the record are always the same, with the floor of the groove level for the whole distance around the disc. The sound waves are cut into the walls of the groove, so that instead of the needle having a vertical movement it has a side-to-side movement (Fig. 26b).

Berliner's method represented a considerable improvement over the early "hill-and-valley" recordings. It

gave far more accurate reproduction with less scratch and as the weight of the sound-box was carried on the bottom of the groove, records were subjected to less wear. In consequence it was possible to use mild steel needles which were far cheaper than the agate or sapphire needles necessary with the earlier recordings.

Unfortunately steel needles are themselves worn in playing a record and experiments have proved that the "shoulders" which are formed in this way on their points, do seriously cut the shellac grooves.

NEEDLES MADE OF JEWELS

Modern researches in recording are, therefore, tending to revert to the "hill-and-valley" method. New ways of suspending the needle arm have been invented and the needle itself carries no weight. Needles made of jewels are very satisfactory. These are much harder than steel and do not wear, with the consequence that the very delicate recording surfaces are not injured. Modern methods of "hill-and-valley" recording permit, moreover, a much deeper cut in the groove (for the wax is thicker at the bottom than it is in the wall of the groove itself) and this results in more accurate reproduction. Finally, by the methods of suspension adopted, "scratch" is almost eliminated.

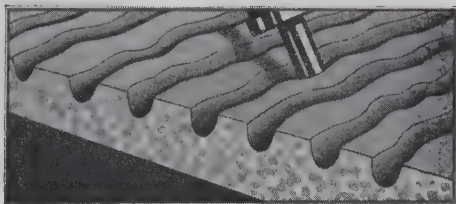


Fig. 26b. "Wall" grooved record of the type invented by Emile Berliner. The needle has a side-to-side movement

CHAPTER 14

LIGHT

THE sun was once worshipped as a god. Today the desire to worship has been replaced by the knowledge that the energy which the sun radiates is absolutely essential to life on this earth. How this energy originates in the sun; traverses the void of space; is absorbed by the green leaves of plants and stored as potential energy in the foodstuffs of all animals is a fascinating story which can be appreciated only after the nature of radiant energy has been understood.

In the seventeenth century two great scientists held theories of the propagation of light through space which seemed to be mutually contradictory. Sir Isaac Newton held that light was emitted as individual corpuscles by its source and that the straight line path of a light beam could be explained by such a hypothesis. On the other hand, the Dutch physicist, Huygens, believed that light is propagated by waves. During the eighteenth century the wave theory was almost completely rejected in favor of the corpuscular hypothesis, mainly because of the great weight which Newton's opinions carried and because facts were yet to be discovered to support the wave theory.

Certainly it is obvious that waves have certain characteristic which particles do not possess. For example, even the very superficial observer is familiar with the way in which water waves curl around the edges of obstacles in their path such as the edge of a breakwater. This is due to the fact that every molecule of water is

moving as the wave pattern passes by, and is, therefore, the center of a disturbance capable of generating waves. Thus the water moving at the edge of an obstacle generates waves which in part curl around the edge. The analogous behavior of light, called diffraction, was discovered nearly a century after the time of Newton and Huygens, by Sir Thomas Young. His discovery was brilliantly explained on the basis of the wave theory by a French engineer, Augustin Fresnel.

Another characteristic of wave motion may be illustrated by a simple experiment. If two pebbles are dropped through the surface of a quiet pond, two series of concentric waves travel out over the surface. When the waves meet and intermingle an interference pattern results. Wherever the crest of one wave meets the crest of another, a crest twice as high results. Similarly, two troughs meeting produce a trough twice as deep. However, when a trough meets a crest no wave motion is apparent. In 1802, Young succeeded in showing that two light beams from a common source produce an analogous result. This is illustrated in Fig. 1. Light from the source passes through the slit, *A*, in the first screen, and spreads out beyond in a series of concentric waves with the slit, *A*, at their center. The light then passes through two slits, *B* and *C*, each the same distance from *A*, in a second. Two sets of waves radiate out from these slits and produce an interference pattern in the space beyond. Along certain

lines the crests and the troughs of each series coincide, producing higher crests and deeper troughs, with an accompanying increase in the intensity of the light. Along other lines the crests of one set of waves meet the troughs of the other and the resulting interference results in no light along these lines. The screen, *D*, placed across these lines will show an interference pattern.

Such experiments illustrating interference and diffraction offer strong evidence of the essential correctness of the wave theory.

THE SPEED OF LIGHT

Before the second half of the seventeenth century it was supposed that light was an instantaneous phenomenon; that is to say, that its speed was infinite and incapable of measurement. That such is not the case, and that light travels at a definite speed, was first demonstrated in a very interesting manner. We have already referred to the four principal satellites of the giant planet Jupiter. As we have seen, in the course of their revolutions around Jupiter, the satellites pass into the great shadow cast in space by this planet. When this occurs the satellites are eclipsed just as our moon suffers eclipse when it passes into the shadow cast by the earth in space.

Watching the eclipse of one of Jupiter's satellites through the telescope, we see the tiny moon grow fainter and fainter and fainter as it passes farther into the shadow, until it finally disappears. When it has traversed the shadow it reappears, emerging as a faint point of light but quickly growing brighter until, when clear of the shadow, its full brilliance is restored.

ROEMER'S WORK

About 1675, Ole Roemer, a Danish astronomer, computed tables to show the times of all future eclipses of Jupiter's satellites, such as may be found today in the *Nautical Almanac*. Having calculated what should occur, he observed the phenomena from time to time. He was astonished to find that although at first the observed

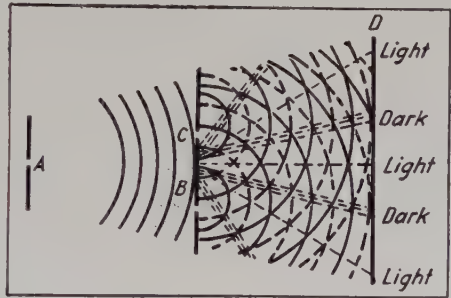


Fig. 1. Diagram of the Young experiment showing that two light beams from a common source produce an analogous result

times of the eclipses agreed very closely with the computed figures, at the end of six months there were considerable discrepancies. Some of the observed times were as much as 16 minutes 40 seconds behind the predicted times. At first no one could offer a satisfactory explanation. After a while, however, it was noticed that there appeared to be a certain regularity in the discrepancies. When the earth was comparatively near to Jupiter, the eclipses occurred on time, but when the earth was in a part of its orbit remote from Jupiter the discrepancies were very pronounced and the eclipses occurred late. At such times—every six months—the earth was at a much greater distance from Jupiter than it had been six months earlier

(Fig. 2). It thus became obvious that the apparent delay in the eclipses must be due to the fact that the light rays from the satellites had to travel a much greater distance. This distance being known—as well as the time taken to cover it—a simple calculation was sufficient to show that light travels at about 186,000 miles a second, and this figure was subsequently confirmed by a series of ingenious experiments by various scientists.

MICHELSON'S EXPERIMENT

One of the most interesting of these (Fig. 3) was carried out by the late Albert A. Michelson. He arranged for a beam of light to be brought to a focus and passed through a slit on to a hexagonal revolving mirror. From here it was reflected by stationary mirrors to a concave mirror. From this point the beam was directed across country where, 22 miles distant, was another concave mirror that reflected the beam back to the

first concave mirror. Here, by means of other mirrors, the beam was directed to a mirror on a revolving drum and then by another stationary mirror to a small telescope. Adjustments were made so that the observer saw the original slit as a bright line on a graduated scale marked in the eyepiece of the telescope. The revolving mirrors were driven at high speed by suitable gearing from an electric motor, and as they rotated they reflected the light as an intermittent beam along its 44 mile path.

It is easy to understand that when the original beam from the revolving mirror is returned to the mirror on the revolving drum it will not find the individual mirrors in the same position as they were when the beam commenced its journey. As the mirrors have moved, the beam will be sent slightly to one side of the telescope slit, so that nothing will be seen. By speeding up the rotating mirrors, however, a point will be

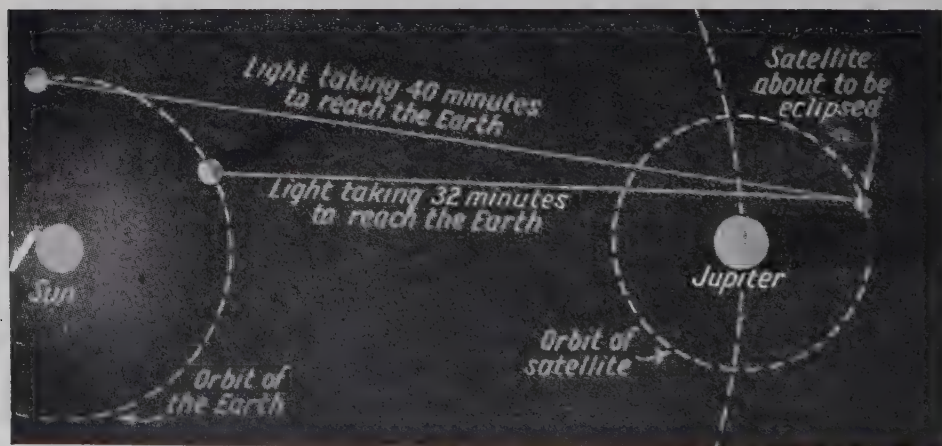


Fig. 2. How the velocity of light was determined by means of Jupiter's satellites. It was noticed that when the earth was further away from Jupiter, the eclipses occurred later than predicted, and it was seen that this was due to the increased distance over which the light had to travel. The diagram is not drawn to scale in respect to either sizes or distances

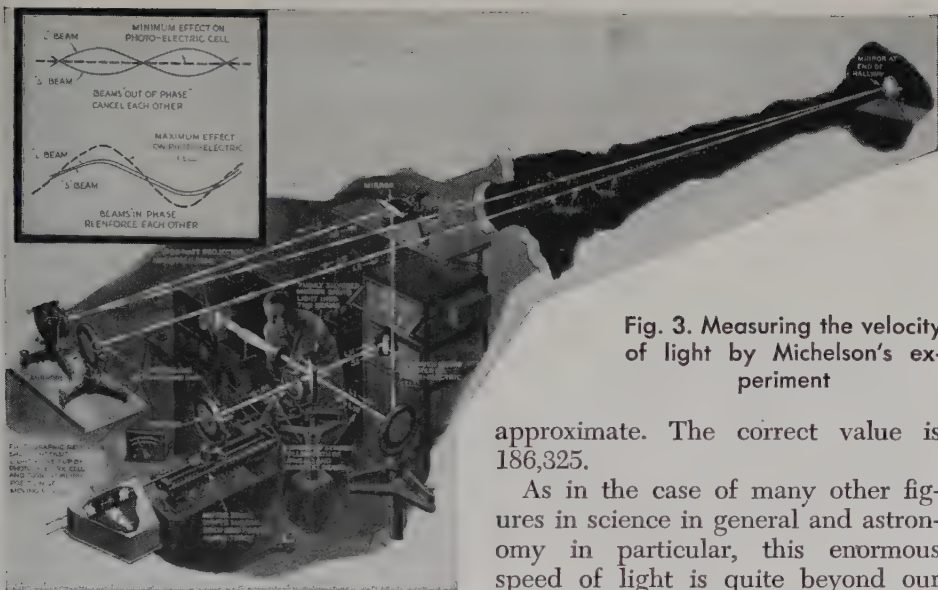


Fig. 3. Measuring the velocity of light by Michelson's experiment

approximate. The correct value is 186,325.

As in the case of many other figures in science in general and astronomy in particular, this enormous speed of light is quite beyond our conception. Our fastest modern airplanes travel at speeds of nearly 500 miles an hour, or 734 feet per second; but this speed is only $1/1,331,000$ of the velocity of light.

REFLECTION

Most of the objects we see are not themselves sources of light. These objects merely reflect the light from some external source such as the sun in the daylight or from an incandescent lamp. The fundamental law of the reflection of light is very simple: the angle of the beam reflected from a plane surface is equal to the angle at which it approached the surface (Fig. 5). In other words, the angle of incidence, i , measured between the line of the incident beam and the perpendicular to the plane, is equal to the angle of reflection, r . A plate-glass mirror is so perfect a reflector that the mirror itself is practically invisible. A mirror's reflection of light coming directly from its source produces the same glare that would re-

reached when the beam will impinge on the revolving mirror, travel the 44 miles, and find that in the meantime the mirror has made $\frac{1}{8}$ of a revolution allowing the first facet of the hexagonal mirror to take the place of the second one. When the mirror-velocity has been so adjusted that this happens, the light will be seen in the telescope.

The experiment, therefore, consists in setting up the telescope so that the light can be seen, and causing the mirrors to revolve at such a speed that the light disappears and then appears again. Then the speed at which the mirrors are revolving is determined.

Let us suppose that the speed is 525 revolutions per second or one revolution in $\frac{1}{525}$ second. Then $\frac{1}{8}$ of a revolution will take $\frac{1}{8 \times 525} = \frac{1}{4,200}$ second—the time required for the light to travel 44 miles. Thus, in one second the light would travel $4,200 \times 44$ miles = 184,800 miles a second. The figures we have taken are only

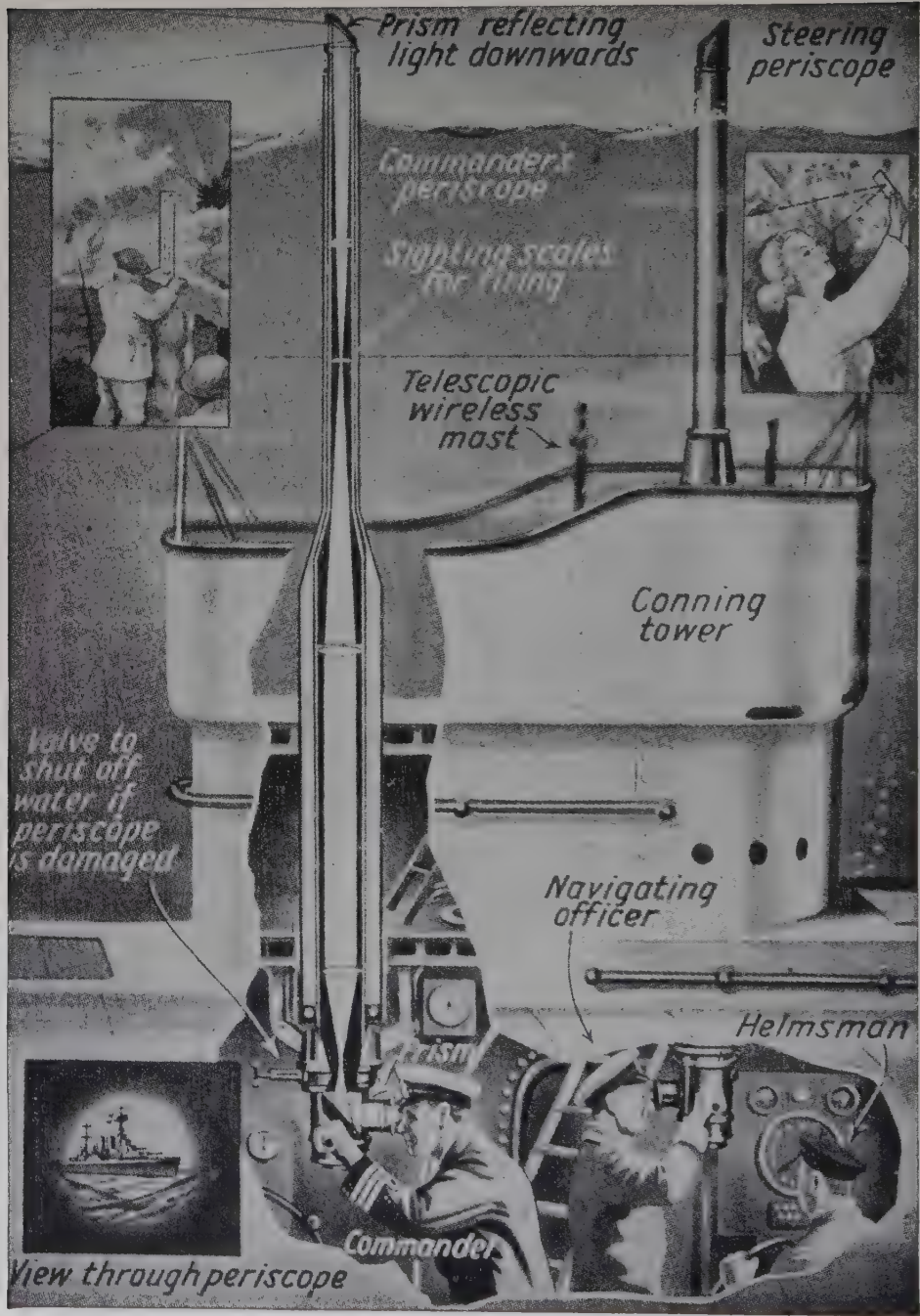


Fig. 4. Use of the prism in the periscope, an instrument to make observations while submerged, as in a submarine (bottom), or under cover, as in a trench (top, left)

sult from looking directly at the source itself. On the other hand, a piece of white cloth scatters the light by reflecting it at many different angles from its rough surface (Fig. 5, bottom) thus effectively removing the glare. Each part of the light beam obeys the law of reflection perfectly when it is reflected from an element of surface of the cloth but, because of the uneven texture of the material, light leaves the cloth at many angles. Any visible characteristic of the light source is obliterated when light from it is reflected from a rough surface. Consequently the surface itself seems to be the source of the light.

Light traveling through a vacuum is invisible. It can make its presence known only when one looks at objects which emit it or which diffusely reflect it. The individual molecules of a gas are far too small to reflect visible light, as we shall see later. Therefore, if it were not for the presence of mist droplets and dust particles in the atmosphere large enough to reflect light, the air would appear jet black and the stars would be plainly visible in the daytime.

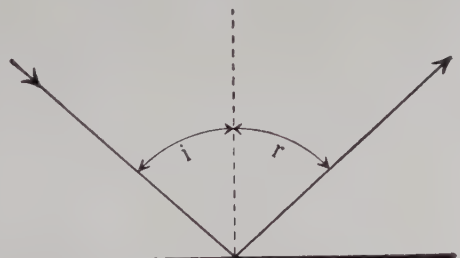
The visible sensation of color is intimately connected with the wave nature of light. The wave length, λ (lambda) is the physical characteristic of the light wave which determines the impression of color which it produces. The human eye is sensitive only to a narrow band of wave lengths which lie between $\frac{1}{33,000}$ and $\frac{1}{64,000}$ of an inch. The wave lengths of the colors of the visible spectrum decrease from the red to the violet end as shown in the table. The limits of the wave lengths producing the impression of each color are arbitrarily defined for one color blends gradually into the next.

TABLE I.—WAVE LENGTHS OF COLORS

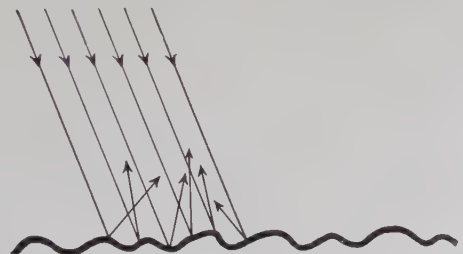
(λ in centimeters)

Red	0.000075	to 0.000065
Orange	0.000065	to 0.000059
Yellow	0.000059	to 0.0000575
Green	0.0000575	to 0.000049
Blue	0.000049	to 0.0000455
Violet	0.0000455	to 0.000039

The visible spectrum is but a small portion of the entire range of wave lengths which characterize light in its broadest sense. The accident which limits the wave lengths to which our eyes are sensitive makes us literally blind to longer wave lengths than 0.000075 centimeter and to those shorter than 0.000039 centimeter. Yet these waves travel through space at the same velocity as visible light and in other ways show its characteristic



REFLECTION FROM A PLANE SURFACE



REFLECTION FROM A ROUGH SURFACE

Fig. 5. Diagram showing difference in light reflection from a plane and rough surface

properties. But before the complete spectrum of wave lengths is discussed, it might be well to consider the fundamental nature of the wave motion by which light is propagated through space. After all, what is doing the waving?

THE "LUMINIFEROUS ETHER"

Light travels through the vacuum of interstellar space more readily than through any material medium. Once its fundamental wave nature was established, physicists were hard put to it to find any material in a complete vacuum as the medium for the wave motion. So they invented the "luminiferous ether" and endowed it with properties which it must have to transmit a wave motion. It must pervade all space, even the space between the atoms and the molecules of material substances, for light travels through transparent bodies. This is not a unique procedure in scientific reasoning. Chemists have invented atoms and molecules to explain the facts which they study and these hypothetical entities have proved exceedingly useful, not only in interpreting facts already known but also in predicting the existence of new ones. However, the theory of the existence of the luminiferous ether has never been substantiated. Every attempt to prove its existence by experiments, based upon what ought to be true if it did exist, has been a failure. The Michelson-Morley experiment, designed to discover whether or not a part of the ether was carried along by the earth's rotation, showed no indication of an ether drift. Modern physicists, following the lead of Einstein, believe that no material medium such as the ether causes the propagation of light.

The true explanation of the nature of light waves developed from the original discovery, in the early nineteenth century by Hans Christian Oersted, that a current of electricity flowing through a wire exerts a magnetic influence in the space about the wire, or, to use the terminology of science, is surrounded by a magnetic field. If the magnetized needle of a compass is brought near an electric current, it takes a position at right angles to the direction of the current. Michael Faraday, continuing the work of Oersted, succeeded in deriving all the fundamental relationships between electrical and magnetic fields. His experimental work was excellent but his knowledge of mathematics was rather elementary, so that his explanations were in terms of mechanical pictures rather than mathematical analysis. Later, about 1865, James Clerk Maxwell subjected the experimental work of Faraday to a brilliant mathematical analysis and succeeded in showing that the rate at which electromagnetic effects are propagated through space is the same as the velocity of light. This result offered strong evidence of the electromagnetic nature of light waves. In 1887 a German physicist, Heinrich Hertz, showed that an electric discharge is oscillatory in character and produces electromagnetic waves which move out from the discharge with the velocity of light. The wave length of such waves is of the order of several hundred meters—approximately one-fifth of a mile! These are the waves which are used today in radio broadcasting.

Light, or radiant energy, is a wave motion in no material medium, therefore, but rather a transmission of energy by means of a wave motion of

an electromagnetic character. To put it rather crudely, if particles of matter can take part in the propagation of a wave, we should offer no strenuous objection to a theory which postulates the transmission of pure energy through space by a wave motion.

ELECTROMAGNETIC SPECTRUM

No single source is known of radiant energy capable of sending out into space all wave lengths of light from the gigantic "ocean rollers," or Hertzian waves, to the shortest waves known, the γ (gamma) rays, which accompany radioactive changes. Further, no super-prism is known which could spread out light of all wave lengths into a complete spectrum. However, we may imagine light from such a hypothetical source passing through such an equally hypothetical prism and spread out into a complete spectrum of electromagnetic waves as shown in Fig. 6. The boundaries of each band of light are more or less arbitrarily defined by the means whereby that type of radiant energy can be generated. Indeed, it will be noticed that there is some overlapping of zones. For example, X-rays may be produced in X-ray tubes of sufficiently high voltage which have smaller wave lengths than some of the γ -rays from radioactive sources.

The frequency, ν (nu), of a certain wave length of light is the number of waves, sometimes called cycles, in the distance covered by the light in one second. It is equal, therefore, to the wave length divided into the velocity of light, the distance covered per second. Hence the longer the wave, the fewer the number of waves per second, and the lower the frequency. For example, a certain radio station broadcasts on a wave length

of 300 meters. Light travels at the rate of 300,000,000 meters a second. Dividing the wave length into the velocity of light, we obtain a frequency of 1,000,000 cycles per second. Since a kilocycle is 1,000 cycles, this frequency is equal to 1,000 kilocycles

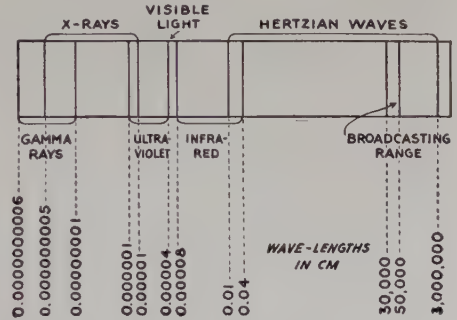


Fig. 6. Diagram of the complete spectrum of electromagnetic waves

per second. In the short-wave broadcasting band a wave length of 10 meters corresponds to a frequency of 30,000,000 cycles, 30,000 kilocycles, or 30 megacycles (1 megacycle is 1,000,000 cycles) per second.

INFRARED LIGHT

When a solid is heated to a temperature above that of its surroundings, it begins to radiate energy into space as infrared light at a rate faster than such rays are absorbed from the surrounding space. At first these are of very low frequency but, as the temperature is increased, shorter and shorter wave lengths are added until at about 500° to 600° C. short enough wave lengths are emitted to be visible. These, of course, are in the red end of the visible spectrum. In other words, the solid becomes red hot. A further increase in temperature adds shorter and shorter wave lengths until all the colors are emitted

and the solid is white hot. This occurs at about $1,500^{\circ}\text{C}$. Solids heated to extreme incandescence, as in an electric arc, not only emit all wave lengths of infrared and visible light but also wave lengths in the ultraviolet band. Hence the use of carbon arcs as a source of ultraviolet light.

The infrared rays which a hot body emits are invisible, and do not affect ordinary photographic film, but they are readily absorbed by matter and converted into heat. Hence they are sometimes called heat waves because of the effect that they produce. It must be remembered, however, that they are in reality light. Infrared rays raise the temperature of our skin and hence produce the sensation of warmth. They are sometimes used therapeutically for this reason but, since their effect does not penetrate much below the surface, their value has been perhaps overestimated. The hot-water or steam radiators used in heating interiors of buildings transmit their energy mainly through infrared radiation and not by conduction via the molecules in the air.

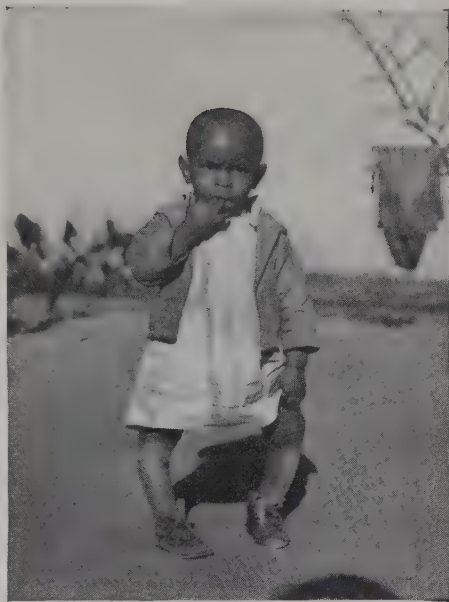
Infrared light may be focused by means of copper reflectors much as the visible light of the bulb in an automobile headlight is focused by a reflector. This means of localizing the heating effect of infrared light is already being used in certain stores in New York, where the light is directed towards the salesgirls behind the counters while the customers in their overcoats are comfortable at a lower temperature in front. The day is perhaps not far distant when the air in our homes may be kept at a low, invigorating temperature while the walls and ceiling conceal infrared light sources which warm the occupants of the room.

ULTRAVIOLET LIGHT

A solid heated to temperatures of the order of 2000°C . emits radiation of even smaller wave lengths than the shortest visible violet light. Because of its high temperature, the sun sends out into space large amounts of energy as ultraviolet radiation. The earth's atmosphere absorbs and converts into heat the energy of this ultraviolet radiation of wave lengths shorter than 0.00003 centimeter. Many substances, which transmit visible light and hence are transparent, absorb ultraviolet radiation and are, therefore, opaque to this type of radiation. Window glass is opaque to ultraviolet radiation, but the more expensive quartz glass lets it through.

The ultraviolet region of the complete spectrum has been more or less arbitrarily defined to include light of all wave lengths between 0.00000135 centimeter and 0.00004 centimeter. Arc lights and quartz-mercury-vapor lamps are the most convenient sources of this type of radiation. Mercury vapor, when excited to luminescence by an electric discharge, emits radiation rich in ultraviolet in addition to visible light of blue color. If the tube in which the vapor is confined is made of quartz, the ultraviolet radiation is not confined by the walls of the tube. This type of radiation is dangerous to the eyes, causing temporary and even permanent blindness. Hence goggles of glass should always be worn when ultraviolet lamps are in operation.

Such lamps have their uses in physiotherapy. Moderate exposure to ultraviolet light of not too great intensity is beneficial to man. Prolonged exposure is harmful. The brown pigment which develops in the skin as a result



Farm Security Administration

Fig. 7. Rickets is a disease which attacks and twists the legs of children suffering from a deficiency of vitamin D. Negro children, because of the greater pigment in their skin, respond less readily to the beneficial rays of the sun

of exposure is in a sense a defense against too intense an exposure of the delicate tissues which lie beneath the skin.

Many of its effects are beneficial, however. Rickets has always been a distressing disease of childhood. It results in misshapen bones due to a defect in the mechanism by which the growing body controls the development of its bony structure. It is a disease which seldom develops in the tropics and then only when children are kept out of the health-giving rays of the sun. Hutchinson and Shole found that the children of the laboring class in India never develop rickets. However, those of the high-caste Hindus develop severe cases since, due to the religious custom of purdah, they are kept in seclusion with their mothers.

Rickets is in reality a vitamin-deficiency disease due to the lack of vitamin D (Fig. 7). This vitamin is synthesized in the human body only by the agency of ultraviolet light.

Ultraviolet radiation is, of course, invisible. It does affect the photographic film and produces fluorescence in certain substances. These absorb the energy from the radiation and re-emit some of this energy as visible light. Thus quinine sulphate emits a blue light when irradiated with ultraviolet. This effect is especially beautiful when a screen of a material opaque to visible but transparent to ultraviolet light is used to cut off all visible light.

X-RAYS

X-rays are of wave lengths between five thousand-millionths and one mil-

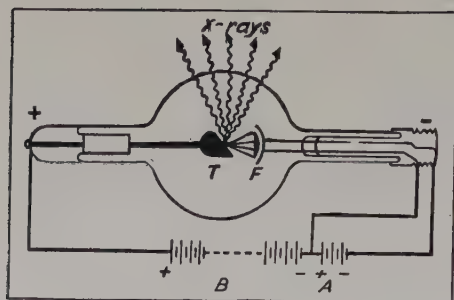


Fig. 8 Diagram of a modern X-ray tube

lionth of a centimeter. They are generated by the sudden stoppage of high-speed electrons. A modern X-ray tube is shown in Fig. 8. A stream of electrons is emitted from the electrically heated filament, *F*, which is negatively charged with respect to the positively charged target, *T*. This target is made of some dense, high-melting metal, like tungsten. The attraction of the oppositely charged target increases the speed of the electrons. Their kinetic energy is changed into X-radiation when they strike the target. The greater the voltage applied to the tube, the higher the speed of the electrons and the shorter the wave length of the X-rays produced.

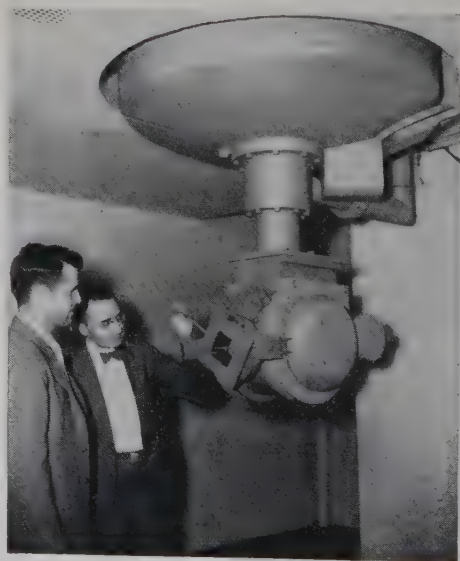
X-rays owe their usefulness to the comparative ease with which they are able to penetrate materials which are opaque to light of longer wave lengths and to their ability to expose the photographic plate. The use of X-ray photography for diagnosis by the dentist and the physician is well known. X-ray photographs are also used by the metallurgist to detect flaws in metals and alloys. Exposure of the skin to X-rays is dangerous, for they cause painful, slow-healing sores.

Gamma rays are radiations of yet shorter wave lengths than X-rays. They are emitted in certain radio-

active disintegrations and have greater penetrating powers than X-rays. They, too, have been found to be of use in the treatment of cancer, for they destroy cancer cells but do not injure normal tissue to the same extent. By the use of extremely high-voltage X-ray tubes, such short X-ray wave lengths can be generated that they are comparable to those of gamma rays. These high frequency X-rays are also being used in the treatment of cancer.

REFRACTION

Light of all wave lengths travels at the same speed in a vacuum but is slowed up when it enters a material medium. It travels about two-thirds as



Memorial Hospital of New York

Fig. 9. Million-volt X-ray apparatus, the first of its kind, was installed in the New York Memorial Hospital in June, 1939. Here it is examined by Dr. G. Failla, of the hospital staff, and H. A. Kent, technician. Much of the apparatus extends through the ceiling to the room above

fast in glass and about three-quarters as fast in water as it does in air. For this reason, when a beam of light strikes a water surface at an angle, the path of the beam is bent. This process is called refraction and can be explained by a simple analogy. Imagine a column of soldiers marching across a smooth parade ground and approaching a plowed field at an angle (Fig. 10). As the soldiers in the front row enter the rough ground their advance is slower but those still on the smooth ground continue as before. The result is that the row is swung into a line more nearly parallel with the edge of the plowed field. Each succeeding row behaves as did the first so that the column is moving in a slightly different direction in the plowed field.

When the column leaves the rough field again and enters another smooth

one the reverse process will take place. The first soldiers to leave the rough going will move ahead faster and the line will swing back to the original direction. The narrower the plowed field, the less it will affect the change from the original line of march. So a light beam passing through a comparatively thin pane of glass whose sides are parallel will suffer little distortion.

The angle through which a beam of light is refracted when passing from one medium into another depends on the wave length of the light. The shorter the wave length the greater the angle of refraction. This difference in the degree of refraction may also be explained in terms of our analogy. If the column on the march is made up of men and boys, the latter will be retarded more than

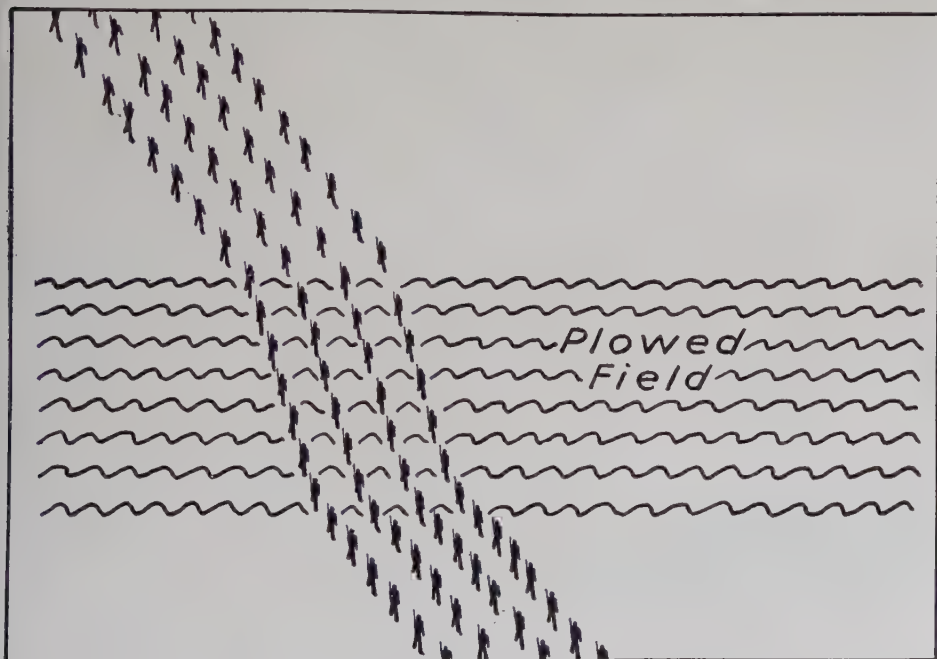


Fig. 10. Soldiers marching across a plowed field—a diagrammatic explanation of refraction. (See text)

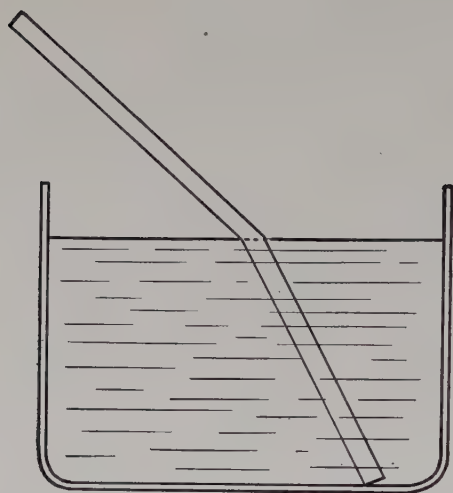


Fig. 11. A stick in a glass of water seems to be sharply bent, due to refraction

the former, so that the line of boys will be bent more from the original path than that of the men.

Refraction gives rise to many interesting phenomena. Often it will be noticed that stones seen at the bottom of a shallow pool appear to be displaced and nearer to the opposite bank than they really are, owing to refraction. Although the light from the stones has traveled directly to our eye, it has been bent in passing from one medium (the water) to another (the air).

We have an instance of the truth of the old saying that "things are not always what they seem" when the sun is setting, for when the last tip seems about to disappear, actually the sun is well below the horizon (Fig. 12). This, too, is due to refraction and it affects not only the sun—at sunrise as well as sunset—but all the heavenly bodies also. Thus, the sun, moon, and stars appear to be above the horizon at their rising and setting, when actually they are below it. The phenomenon may be illustrated by placing a coin in a basin and walking away from it until a place is reached where the coin just cannot be seen over the edge of the basin. If a friend now fills the basin with water, the coin will immediately become visible to the observer. The rays of light from the coin are, of course, refracted by the surface of the water (Fig. 15, page 318).

DISPERSION

When a beam of light made up of all wave lengths of visible light passes from air into glass, the longer waves at the red end of the spectrum are refracted least and the shorter waves at the violet end most, with intermediate colors somewhere in-between. The result is a dispersion of the beam

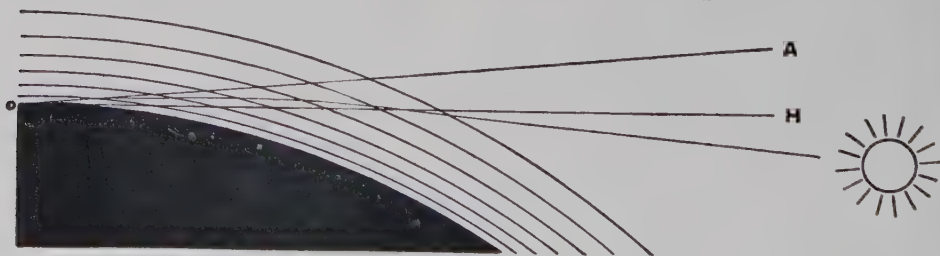


Fig. 12. When the setting sun is visible just above the horizon, it is actually below it, but the light-refracting powers of the atmosphere make it appear above it. In the figure, *H* is the horizon-level and *A* the apparent position of the sun, which is actually below the horizon

of white light into its constituent colors. The use of a glass prism to analyze a beam of light makes use of the dispersion that occurs at the two surfaces at which the light enters and leaves the prism (Fig. 13).

In 1854, Bunsen and Kirchhoff, at the University of Heidelberg, invented an instrument called the spectroscope, by the aid of which a beam of light may be resolved into its constituent colors (Fig. 14). The light to be analyzed passes through a vertical slit in the collimator, *C*, and leaves through a lens adjusted to produce a beam of parallel rays. It is then dispersed by the prism, *P*, after which a second lens focuses each color as an image of the slit against a dark background at the eyepiece. Light of a given wave length always arrives at the same position and a scale, graduated in wave lengths, is set in the eyepiece above the place where the colors are focused for study and examination.

PHENOMENON OF "LOOMING"

In connection with terrestrial objects, there is an allied phenomenon known as "looming." The rays of light from objects below the horizon are so refracted that distant objects—ships or villages, for example—nor-

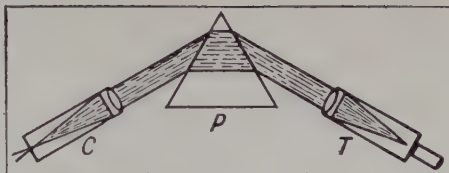


Fig. 13. Dispersion of a beam of light caused by a glass prism

mally invisible because they are below the horizon seem to be raised above it. This is probably caused by the atmosphere being in contact with water or land that is at a lower temperature.

In the Polar Seas, ships actually below the horizon have been seen as if raised well above it. William Scoresby, the Arctic explorer, told how, when cruising off the coast of Greenland, he saw every detail of the ship "Fame," although it was actually 17 miles below the horizon. On another occasion when the British ship "Archer" was cruising in the Baltic, the whole of the British fleet was seen as though suspended in the sky upside-down, when at the time it was 30 miles distant. At Mauritius a pilot once saw a vessel when it was actually 200 miles from him, and on another occasion the Bombay packet was sighted from Aden when 200 miles off.

From the sea's edge at Zoppot, a small port near Danzig, the inhabitants sometimes see the peninsula of Hela with its village and lighthouse. This place is 25 miles from Zoppot and is therefore really below the horizon. The good people of Zoppot do not regard this as an optical illusion but as evidence either of their keen sight or of a very clear day.

One of the best examples of this class of phenomena is the *fata Morgana* that is occasionally seen across

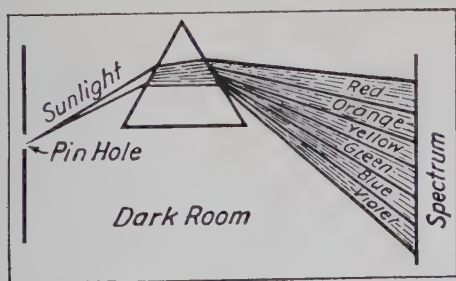


Fig. 14. Analysis of sunlight into its component colors by use of a spectroscope

the Strait of Messina from the coast of Calabria. The spectator apparently sees lofty castles, towers, and palaces; or villages and trees, with cattle grazing in wide plains. The explanation lies in the "looming" of parts of the town of Messina, which are thus rendered visible to the inhabitants across the strait near Italy's toe.

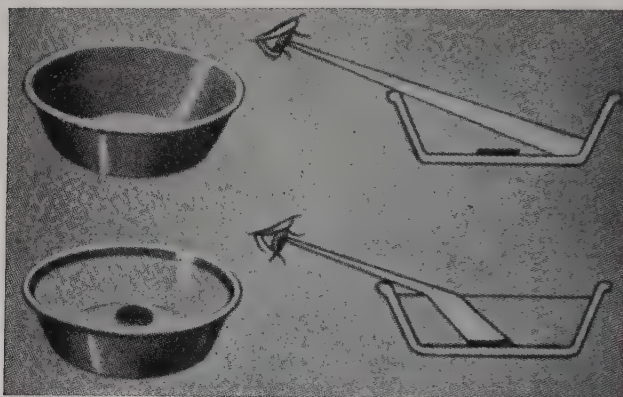


Fig. 15. Water refracts light. The upper bowl is empty and since the line of vision is straight, the coin is invisible; the lower contains water and the line of vision is bent downward. The coin is therefore seen without any great difficulty

At various times "looming" has been reported in England, especially on the south coast. From Hastings, the French coast of Picardy, 45 miles distant, has been clearly seen extending from Calais and Boulogne to as far south as Dieppe. From Dover, the cathedral and Napoleon Column at Boulogne have been seen, and once with a telescope a train was seen to leave Boulogne and travel towards Calais. The churches and buildings of Hull, in England, and shipping on the Humber, have been seen from Bridlington, 32 miles distant, and on one occasion the town of Grimsby was clearly seen, although 40 miles distant.

Another class of optical phenomena of the same order is also due to refraction and is explainable by the laws of optics. When the lower strata of the atmosphere become heated by contact with the land, they expand so that some of the rays of light from a distant object are refracted, while other rays that do not pass through the heated strata travel in the normal way. To the observer the distant object is then seen as though it were in two positions. Once, on the savannas, or plains of South America, part of a herd of oxen feeding about a mile away appeared to be suspended in mid-air, the remaining animals appearing in their normal positions. Sometimes the effect is of an image seen in duplicate, one image above the actual object,

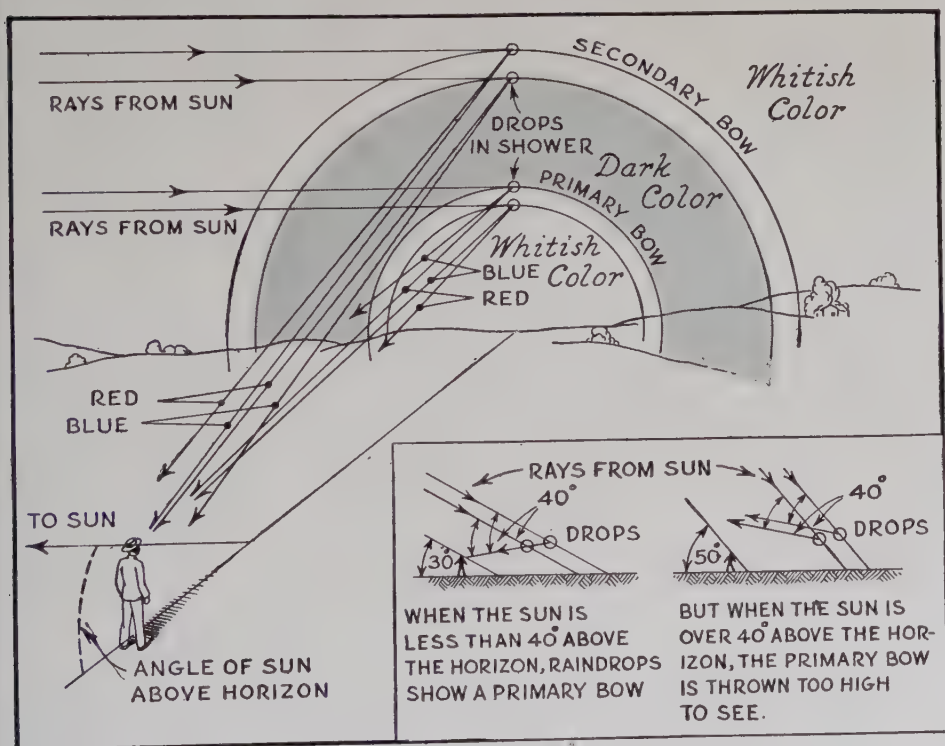
which is, of course, invisible, and the other above the first, but inverted.

Variations in the temperature of the atmosphere cause differences in its density and consequently its refractive powers also vary. Extreme changes due to local heat or cold may cause extraordinary optical phenomena such as mirages (French: *se mirer*, to be reflected), seen in deserts and in polar regions. Often desert mirages are so realistic that even experienced travelers have been deceived, imagining lakes or water where none exists. Such deceptive mirages have been known from the earliest times and are mentioned in the Koran.

REFRACTION AND THE SUN

It is also due to refraction that the sun sometimes appears oval, or curiously misshapen, when low down in the sky. This is explained in the following way. At the point immediately overhead—the zenith—there is no refraction, but it increases towards the horizon, where it is greatest because the more obliquely light enters the atmosphere, the greater is the refraction. Consequently, the rays from the lower parts of the sun are refracted to a greater extent than those from the upper part. This has the effect of causing it to appear oval both at sunrise and sunset.

A rainbow, which is also due to refraction, occurs when the sun's rays, shining on very small drops of water in the atmosphere, are bent and split up into their primary colors on passing through the drops (Fig. 16). Here the water acts exactly as a prism splits up a ray of light to form a spectrum, as we shall shortly describe, the raindrop representing the prism and the background representing the screen on which the spectrum is projected. Certain conditions are necessary for the production of a rainbow. The sun's rays must impinge on the falling rain; the sun's altitude must be less than 45° ; and the spectator must be interposed. The rainbow al-



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Fig. 16. Diagrammatic explanation of the mystery of the rainbow. Figure is explained on this page

ways appears in the region of the sky opposite to the sun and occurs when the sun is shining and rain falling at the same time, although it is not necessary for the rain to be falling in the place where the observer is standing. As a line from the sun to the center of the arch will pass through the head of the spectator, it follows that each person will see his own rainbow.

Sometimes a double rainbow is seen—a perfect rainbow that presents the appearance of two concentric arches. The brightest, the “primary,” is always red on its outer edge and violet on its inner edge, the other colors being arranged in their correct order between, as in the spectrum. Outside the primary may sometimes be seen the secondary bow with colors in the reverse order, the red being on its inner and violet on its outer edge. In such a case the primary bow subtends an angle of 41° at the observer's eye and the secondary bow an angle of 52° .

As the moon reflects sunlight it follows that if the conditions are suitable there can be a rainbow at night. Lunar rainbows, as these phenomena are called, are sometimes seen, and they do not differ in the theory of their formation from solar rainbows. They are less bright, but the full range of colors from red to indigo can be seen when conditions are favorable.

DIFFRACTION OF LIGHT

We know that we can hear a sound even when the source of the sound and our ears are not in an uninterrupted straight line. In other words, sound waves can turn corners. But such is not the case with light, and we are led to wonder why this is so,

seeing that light, like sound, is propagated in waves. The fact that light does not bend round a corner was held to be one of the chief objections to the undulatory (wave) theory of light, when it was first brought forward.

SOUND WAVE DIMENSIONS

The explanation lies in the fact that in the case of sound the wave lengths are almost comparable with the dimensions of ordinary objects—middle C on the piano, for instance, produces waves about 4 feet 6 inches in length. In the case of light, however, the wave lengths are infinitely smaller. For example, the length of the wave that produces the yellow light of sodium is over 2,000,000 times smaller than the sound wave of middle C. Most objects that are placed in the path of a ray of light are of much greater dimensions than the length of a light wave. Light could be made to “bend round a corner” if the light ray were passed around some object that is comparable in size with the wave length of light.

To a certain extent this can be demonstrated by allowing a ray of light to enter a darkened room alternately through two metal plates, the beam being directed on to a sheet of cardboard standing parallel with the metal plate. If a wide slit is cut in one of these plates it will be seen that the resulting image on the cardboard is sharp and clear at its edges. In the second metal plate an extremely narrow slit is cut, say with a sharp penknife or a razor blade. The resulting image on the cardboard will be seen to be bordered by a series of alternately dark and bright bands that extend into the surrounding area. The fact that with the nar-

rower slit the surrounding area does not remain entirely unilluminated shows that to a certain extent the light has bent around the edge of the slit. This bending effect is known as "diffraction."

There is a recently developed material, known as polaroid, that has some remarkable properties. In appearance polaroid is a thin, transparent film that looks and feels like celluloid, but is somewhat darker. A sheet of polaroid is actually an assemblage of needlelike crystals, several thousand billion of which are embedded in a square inch of the material. All these crystals lie parallel and they are so small and so closely packed together that the actual structure of the sheet cannot be seen unless magnified over 1,000 times by a microscope.

WHAT IS POLARIZATION

A sheet of this material "combs out" the light that passes through, arranging the rays so that they are all in parallel planes. The effect of this, called polarization, is similar to that of random waves moving along a rope, tied at one end, and moved about in all directions at the other. If the rope passes through a gap in a fence, all the vibrations will not get through but those that do will all be parallel with the gap between the palings. In practice, the light beam's "fence" is polaroid, and after light has passed through it the vibrations are all arranged on the same plane. This arrangement of the vibrations on one plane that makes them controllable, for when a second "fence" of polaroid is placed in the path of light, with its holes at right angles to that of the first sheet, the vibrations cannot pass and no light gets through (Fig. 17).

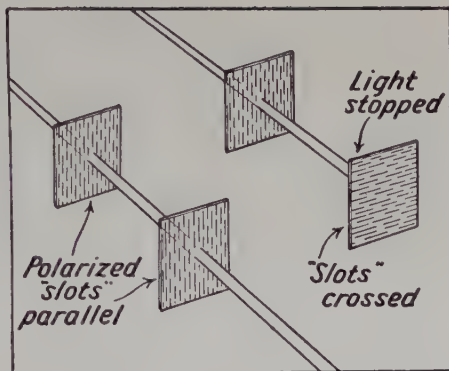


Fig. 17. (Left) Light passing through two sheets of polaroid, arranged so that the "slots" are parallel. (Right) With slots of second sheet at right angles the light beam is completely cut off

To the eye, light that has passed through polaroid looks like ordinary light. Nevertheless, it can be made to do many things that ordinary light cannot be made to do. It can be used to detect strains, for when glass and other transparent materials are subjected to stress they develop quasi-crystalline characteristics corresponding in degree to the amount of strain. When viewed between crossed sheets of polaroid, the strained areas appear in white or color against the black of the rest of the field. If strains exist in a bottle, for instance, the areas where they occur show up (Fig. 18).

POLARIZATION IN INDUSTRY

There are many other industrial uses of this new material. Manufacturers can detect faulty processing; users of glassware can determine its quality before they buy it. By applying to a model forces that correspond to the forces that will occur in service, an engineer can discover how efficiently the members he is designing will carry the loads they will meet

in service. Strains appear as a map of light and dark bands in the model, and from this map the strain at every point can be calculated so that the behavior of the full-size parts in service can be predicted.

Blinding headlights are held to be responsible for the loss of tens of thousands of lives every year. When the form of polaroid designed for

are parallel. But when two cars, equipped in this way, meet each other on the road, neither driver sees the direct light of the approaching headlights. Parallel when the cars are headed the same way, the slanted optical slots of the polaroid are now crossed at right angles because the cars are facing each other. Light from the approaching headlights can-

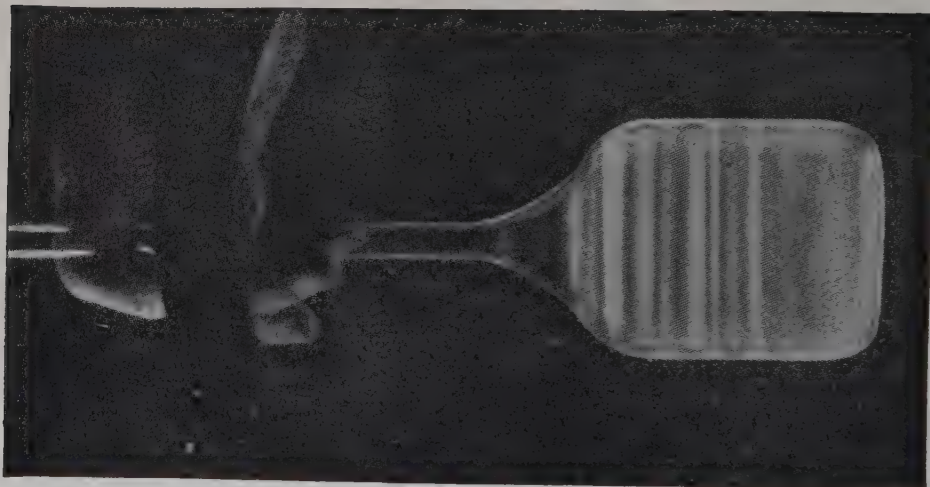
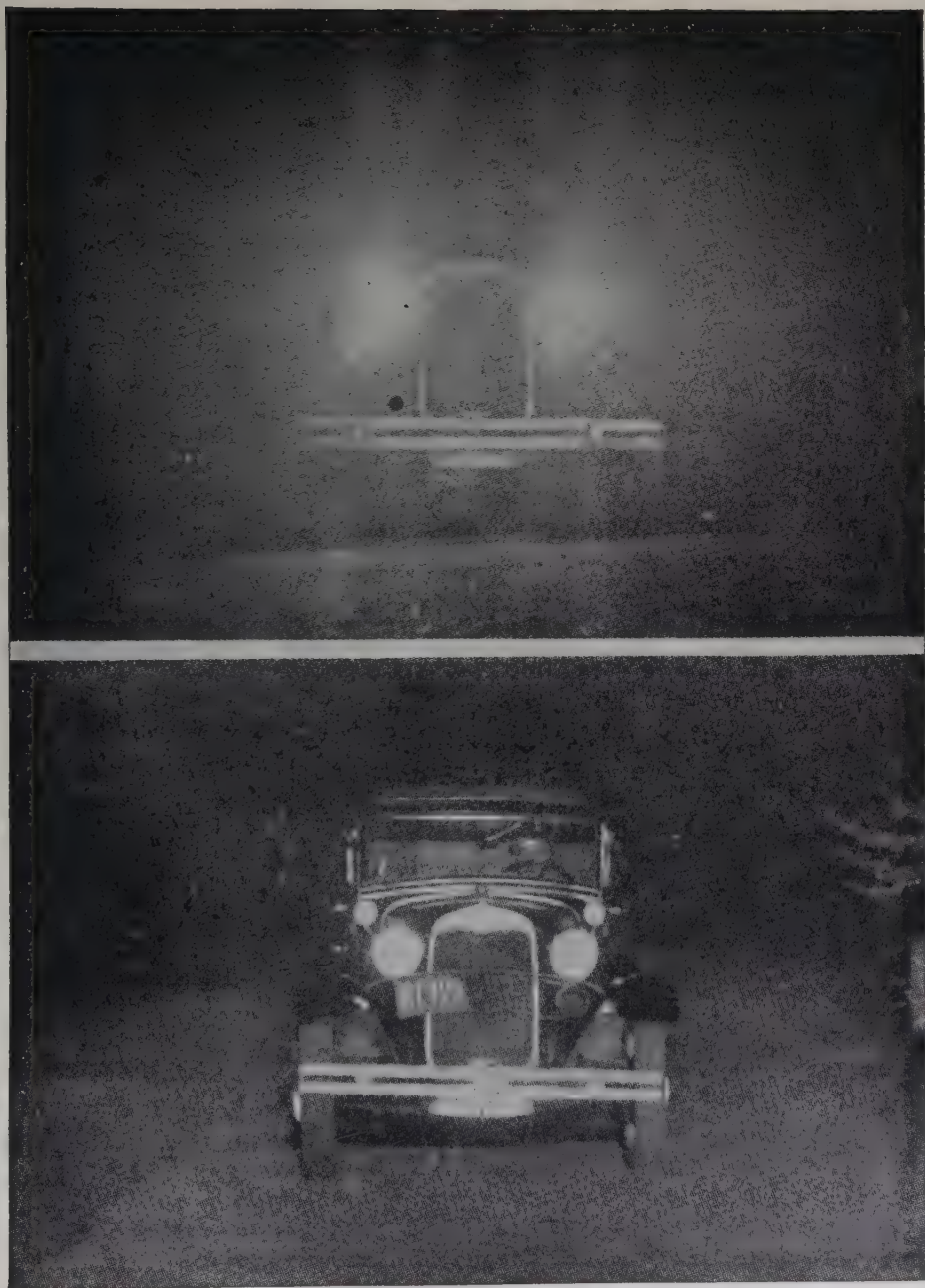


Fig. 18. A bottle showing concentric bands of internal strain when inspected between crossed polaroid discs. Because of its capacity for showing up flaws, polaroid is valuable to manufacturers. See text on page 221 for complete explanation of picture

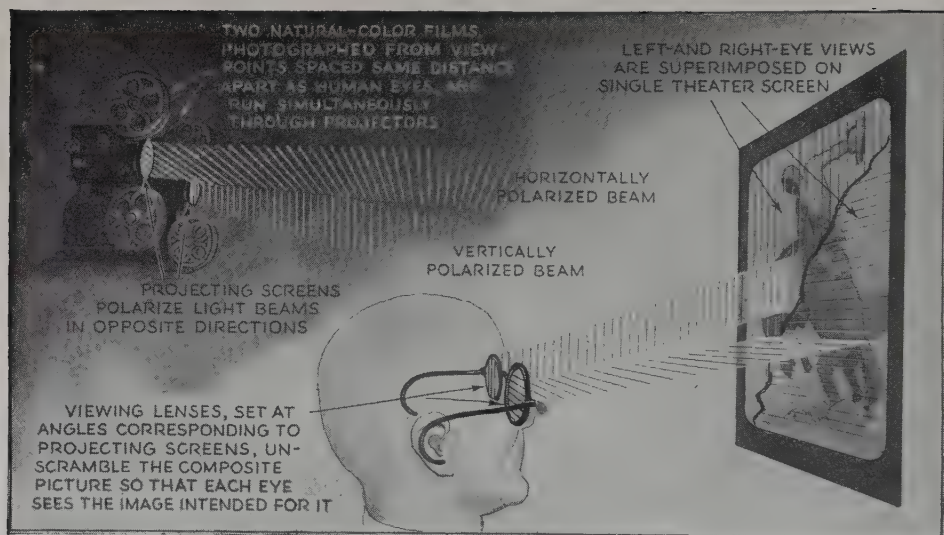
automobile headlights is released, most of these lives will be saved, for it will be possible to eliminate headlight glare. Each car will be fitted with a windshield of polaroid, with its "slots" arranged at an angle of 45° to the road. The headlights are fitted with polaroid lenses with their slots at exactly the same angle. The combed light goes out from the headlights, strikes the road and is reflected back through the polaroid windscreen to the driver, who gets the benefit of his own headlights, because windshield and headlight slots

not get through the windshields and all glare is eliminated (Figs. 19 and 20). However, it must be remembered that only that fraction of the light, vibrating parallel to the "slots," gets through. The rest of the beam's energy goes to heat. The glare is eliminated but so is much of the light.

With a single polaroid screen over his lens, a photographer can photograph obliquely through glass and water, thus reducing unwanted and ugly surface reflections and glare. By rotating the screen to the correct angle, he can subdue bright oblique



Figs. 19 & 20. How polaroid will help the motorist to see properly at night, and thus reduce accidents caused by glaring headlights. (Top) Car with ordinary headlights. (Bottom) Polaroid headlights and observed through a polaroid windshield. Polaroid completely eliminates the blinding effects of headlights that are the motorist's terror



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Fig. 21. Stereoscopic picture projection. Two views are taken by the camera from two viewpoints. These views are projected simultaneously on to the same screen, one as a vertical and the other as a horizontal view. Observers equipped with polaroid spectacles are enabled to "unscramble" the composite pictures, being thus endowed with stereoscopic vision

reflections that he finds objectionable; and he can darken a blue sky when photographing in a direction at right angles to the sun's rays.

THREE-DIMENSIONAL MOVIES

One of the most interesting developments, however, is in connection with three-dimensional motion pictures. In life, the view seen by the left eye is always slightly different from that seen by the right, as was explained in the consideration of parallax. If two photographic images of such views are projected one over the other, the right-eye view polarized in one plane and the left-eye view polarized in a plane at right angles to the other, observers will see the views as solid three-dimensional forms if they look through polaroid spectacles with the "slots" of the right

and left lenses arranged to correspond.

The ability to reproduce on the screen what the human eye picks up during every minute of normal life—the third dimension or the impression of depth, roundness, and realness of the things looked at—has hitherto been lacking in the movies. In three-dimensional movies, the camera looks at the scene exactly as a pair of human eyes would look at it, and takes two simultaneous views of it. In projection, the two views are shown on the same screen, one over the other. Each image is projected through polaroid, set in such a way that the left-eye image reaches the screen with its light vibrations vertical, the right-eye image with vibrations horizontal (Fig. 21). The audience, supplied with polaroid glasses with the lenses set at

corresponding angles, sees one image with the left eye and the other with the right. Each eye sees one picture and one picture only. The screen itself seems to disappear. The observer feels that he is looking through a great open window at real actors and actresses engaged in real action taking place then and there.

CHEMICAL ACTION OF LIGHT

Light may be produced by chemical action, and conversely chemical changes may be produced by light. This is commonly noticed in the fading of the colors with which many cloths are dyed, particularly when subjected to a long exposure in strong sunlight.

Light is of great importance to nearly all living organisms, and particularly so to plant life. Here, chemical changes are produced by the influence of sunlight, chiefly in the building up of starch from carbon dioxide and water in the leaves of plants. If deprived of light, plants grow white, for they depend on the sun's rays for the variety, beauty, and intensity of their coloring. To man sunlight is necessary for life, health, and strength, the health-giving properties of certain rays in the spectrum near to those of light being evidenced by the very great service they render to medicine.

Light is capable of producing powerful chemical action resulting in definite changes that may be turned to good account. One of the most striking of these is the action of light on salts of silver, by which the salts are decomposed in varying degree according to the intensity of the light acting on them. This is the basis of photography (Greek: *phos*, light; and *grapho*, write). The photographer re-

lies on the fact that some of the compounds of silver—and more particularly its compounds with chlorine, bromine, and iodine—are extremely sensitive to light.

THE MODERN CAMERA

Before describing how a photograph is obtained, let us for a moment consider the mechanical and optical side.

The modern camera is a development of the camera obscura, the principle of which appears to have been known to Euclid about 300 B.C., but which was not given serious attention until the thirteenth century. It consists of a darkened chamber into which light may enter only through a small aperture. The early experimenters discovered that if a chamber was completely shut off from outside light, with the exception of a very small hole in one of the walls, a perfect image of the outside scene was thrown on the wall opposite the small hole. The image was in natural colors but it was upside-down, the reason for which is made clear by the smaller drawing in Fig. 22. Light reflected from the man *A-B* enters the dark box through a pinhole at *C* and is thrown on the back of the box at *D-E*. If we looked from the top of the man's head from the point *A* through the pinhole we should see only a minute portion of the image at *E*. Because our line of vision follows the same straight path as the light ray *ACE*, the portion we should see would be the head of the man. Similarly, if we placed our eyes level with the point *B*, we should see a fraction of the feet of the man in the image at *D*, and the remaining part of the image would be seen at intervening places.

To convert such a dark box into a modern camera it is only necessary to replace the pinhole with a lens and to insert a photographic film (Fig. 22). It is quite practical, in fact, to take a photograph without a lens, by employing only a simple pinhole as a means of forming the photographic image. It has been found, however, that by using a lens the pinhole can be enlarged, as it were, thus admitting more light, greatly improving the image, and allowing pictures to be made under a great variety of conditions. A lens passes parallel rays of light and these converge at a point, called the "focus," the distance of which from the lens is called the "focal length" of the lens. The longer the "focal length" of a lens, the larger is the image of objects on the film, and consequently the less of the subject will be included in the photo-

graph. Conversely, with a shorter focal length, more of the subject will appear but the image will be smaller. The greater the distance of the object from the lens, the nearer the film must be to the lens; conversely, the nearer the object, the farther away the lens must be from the film. It is to adjust these differences that we "focus" a camera. As a rule, modern cameras are fitted with a lens that has a focal length a little longer than the longest side of the film or plate. Thus a $4\frac{3}{4} \times 3\frac{3}{4}$ inches camera will have a lens about $5\frac{1}{2}$ or 6 inches focal length.

PRINCIPLES OF PHOTOGRAPHY

The process by which a photograph is obtained is relatively simple. The light rays from the sun fall upon the subject and are reflected in all directions. The rays coming from any sin-

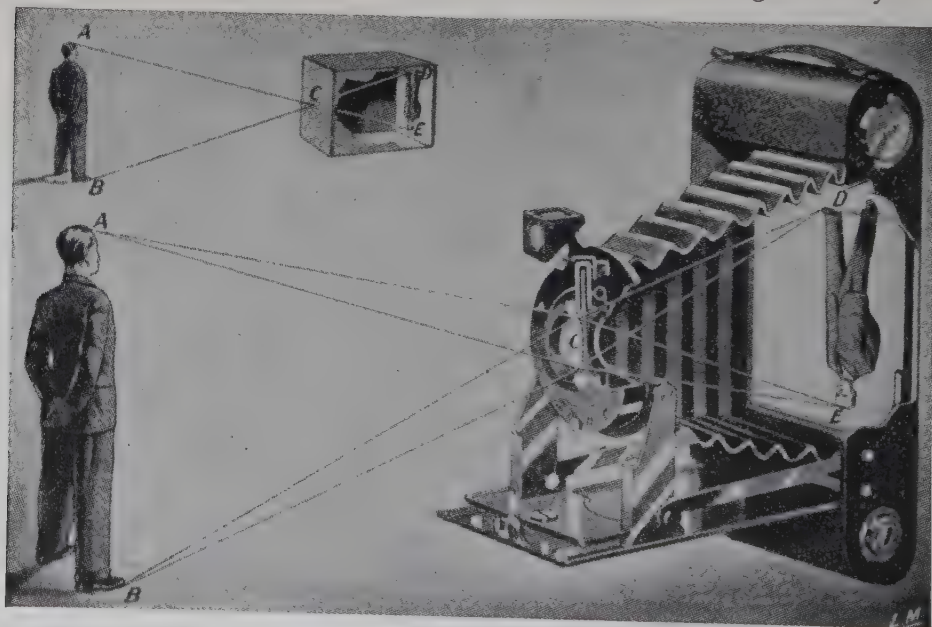
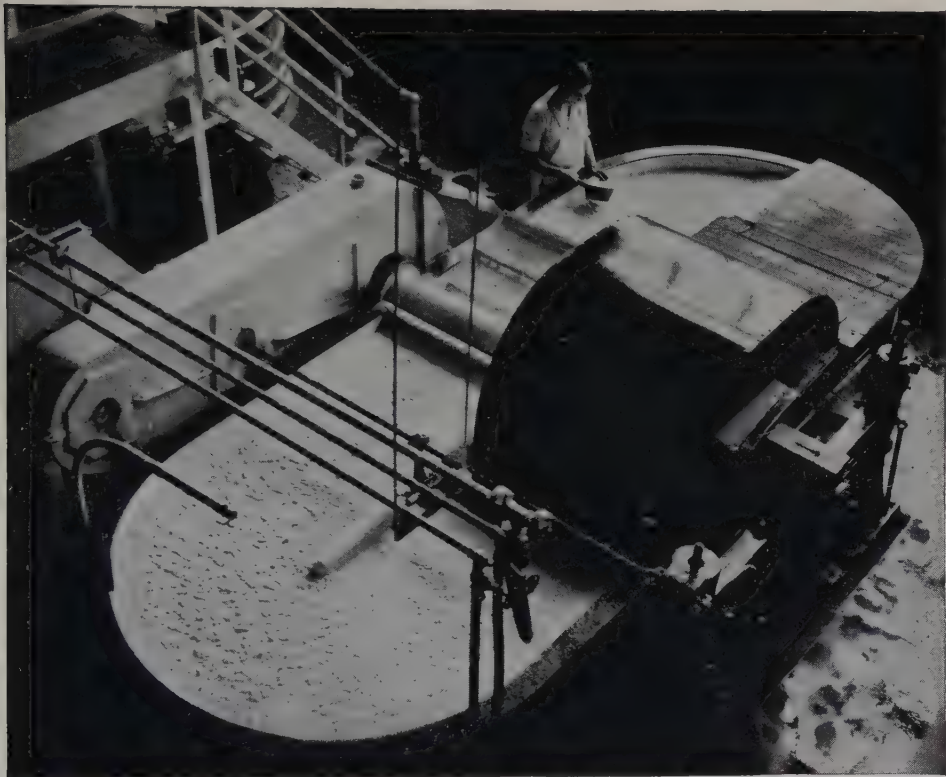


Fig. 22. How a camera takes a photograph. (See text.) A dark box (inset) with only a pinhole in place of a lens will take a satisfactory photograph. Notice that figure of man is seen in reverse on camera plate



Eastman Kodak Co.

Fig. 23. The base of photographic papers is made from purified cellulose fibers, which are here seen going through a beater, preparatory to fabrication on great papermaking machines

gle point of the subject therefore impinge at varying angles on all parts of the lens. In passing through the lens they are refracted, again at varying angles, until they all meet at a point. From the point *A* (Fig. 22) for example, the rays are reflected to different parts of the lens and are collected together at *E*, while those from the point *B* are collected at *D*. Similarly, rays from every other point of the subject are collected from various parts of the lens and concentrated again somewhere within the plane *DE*. Consequently, if we place a photographic film at *DE* a perfect image

of the subject will be reflected on it, but if the film is inserted at any other distance the image will be distorted, or "out of focus," to use the technical term.

In many cameras the distance between lens and film is fixed so that the focus is always correct. In more elaborate cameras, however, which take larger images of objects at varying distances from the lens, it is necessary to adjust the focus. This is done by moving the lens to or from the film until the image is defined with maximum clarity. Actually, for the purpose of focusing, the film is re-

moved and replaced by a sheet of ground glass on which the image may be seen. When correct focus is obtained, the camera "shutter"—a device fitted immediately before or behind the lens—is closed to prevent light coming through the lens and the ground glass is replaced by the photographic film. To take a photograph it is now only necessary to press the shutter control, so opening the shutter for a fraction of a second and then closing it again. During that fraction of time everything within the range of the lens has been faithfully recorded on the plate, every little detail of light and shade having slightly different effects on the highly sensitized film.

The chemical usually employed in making photographic film is silver bromide, one of the class of chemicals known as "silver salts" and a compound of the metal silver with bromine. The silver salt is applied to the film or plate in the form of an emulsion that contains the chemical suspended in a gelatine solution. We can obtain an approximate idea of what happens when the light rays fall on the film if we imagine that the rays tend to separate the compound into its constituent parts of silver and bromine, the extent of this separation varying with the amount of light reaching the film.

WHAT THE DEVELOPER DOES

The rays produce minute changes that cannot be detected by ordinary means and require a developer to render visible the results of the action. Such a developer generally consists of a developing agent, usually pyrogalllic acid (pyro), hydroquinone, or metol. Its function is to bring out the latent image by reducing the sil-

ver salt to metallic silver, or, to express it less scientifically, by blackening those parts affected by the light. Since finely divided silver presents no large reflecting surface it absorbs light and appears black. The developer also includes an alkali—generally sodium carbonate—that acts as an accelerator and gives a greater reducing power to the developing agent, so speeding up the blackening process. Finally, the developer contains a restrainer—such as potassium bromide—to prevent the development of the unexposed silver salts and to act as a preservative, preventing the solution from deteriorating, or oxidizing, while in use.

After development the negative is immersed in a fixing bath, the effect of which is to make it permanent—that is, to "fix it"—so that it can be brought into the light without risk of spoiling—or fogging it. This fixing bath—a solution of sodium thiosulphate—dissolves away the remaining silver bromide that has not been affected by the processes of exposure and development.

We now have the finished "negative," in which all the details of the picture are composed of pure metallic silver, the heaviest deposits of silver being at those places where most light reached the film. That is why all the brightest parts of the original appear black or opaque, when the negative is held up to the light. The dark portions or deep shadows in the photographed scene reflected no light, and as they had no effect on the film, they appear white or transparent.

As the film remains sensitive to white light until it has been passed through the fixing bath, all the operations up to that point have to be

carried out in a ruby light in the photographer's "dark room." Once the film has been safely fixed, positives or "prints," may be taken from it on specially sensitized paper, as many times as desired.

These prints from the negative are obtained by practically the same chemical processes as those used to produce the negative. The paper is coated with a silver salt so that it is sensitive to light, exactly as the photographic film was, although in this case the reaction is much less rapid. A sheet of this paper is placed in a printing frame in contact with the negative, in which position it is exposed to a strong light for a certain period—perhaps a few seconds. The light rays pass through the transparent parts of the negative, so affecting the silver salts with which the paper is coated. The dark parts of the negative obstruct the light, leaving the silver salts unaffected. When developed, the picture appears as a positive with all the gradations of light and shade of the original subject in their correct places. Finally, the print is dipped in a fixing solution so that continued exposure to light will have no further effect on the sensitive chemical, and after being washed and dried, it is ready for mounting.

THE ROLL-FILM CAMERA

The most popular type of camera for amateurs on account of its simplicity and portability is that which uses roll film. This is simply a long strip of celluloid coated with the sensitive silver salt. It is placed in the camera between two spools and as soon as a picture is taken the used part of the film can be wound on to one of the spools and a fresh portion brought behind the lens, and so on

until the entire roll has been completely used.

The origin of photography may be traced to Thomas Wedgwood, who early in the nineteenth century discovered a method of obtaining profiles of figures, stained-glass windows, etc., by throwing their shadows on paper rendered sensitive to the action of sunlight by a coating of

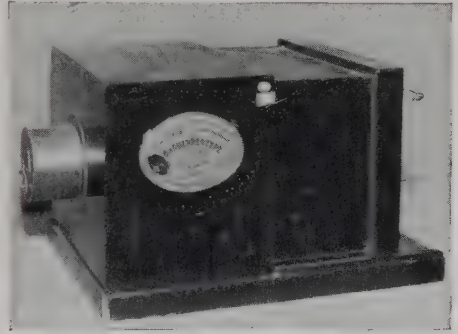


Fig. 24. An early daguerreotype camera

nitrate of silver. He failed to solve the problem of "fixing" the pictures, however, and it was left to a Frenchman, Nicéphore Niepce, in 1822, to produce the first permanent photograph with the aid of a plate coated with silver and bitumen; this was exposed for about eight hours to the image in a camera obscura. The process was improved by Louis Daguerre, who in 1839 produced the first "daguerreotype." (Fig. 24). In this the subject was taken directly on a copper plate and in consequence the image was reversed. Daguerreotypes could not give copies as modern negatives do, nor were they very clear to the vision unless held at a certain angle to the light. They remained popular for very many years, however, and no doubt people at that time considered them marvelous.

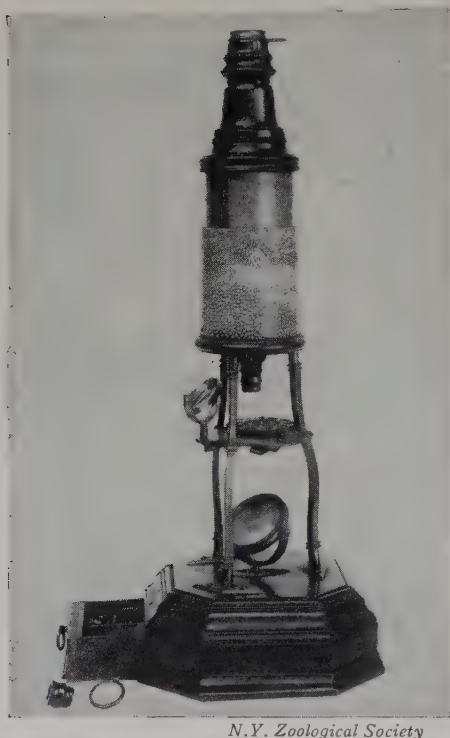


Fig. 25. An eighteenth-century microscope

During the same period, Fox Talbot was steadily working in England. In about 1839, without any knowledge of the previous labors of Wedgwood, he discovered a means of obtaining pictures in the camera by the agency of light. He used paper washed with nitrate of silver, and he also discovered how to "fix" the prints when so obtained. He then proceeded to perfect the method by which "positives" or prints, could be made from the original photographic impression, thus introducing a method practically the same as that in use today.

THE TELESCOPE

Both refraction and reflection are fundamental to the telescope. Let us

see how use is made of these principles.

It has sometimes been suggested that the principle of the telescope was discovered and in use as far back as Babylonian times, but this is very doubtful—as also is the claim by Roger Bacon (1214–94), the Franciscan monk of Ilchester, that the invention was known to Julius Caesar, who, when about to invade Britain, surveyed the new country from the shores of Gaul with a telescope! The popular story is that the telescope was invented—not by Galileo as is often stated—by an apprentice of Hans Lippershey, an optician at Middleburg, in Holland. According to this story, the boy was playing with some spectacle lenses during his master's absence, when he happened so to arrange the lenses that the spire of a neighboring church was magnified. On Lippershey's return the apprentice told him of what he had seen and the optician made the first telescope, in 1608. In the following year Galileo heard of the discovery and made his telescope, after discovering the principle on which it was based. Later, with improved instruments, he made numerous discoveries—the spots on the sun, mountains on the moon, satellites of Jupiter, and many others.

Galileo's telescopes were of the refracting type (Fig. 26). Such depend for their power on the refraction of the rays of the light by a large lens, or "object glass" as it is called. A lens of the single positive type has both surfaces curved and inclined to one another at every part except the center, where they are parallel. When rays of light enter the lens they are refracted. They are not restored to the same general direction when they leave it, however, as in the

case of a sheet of plate glass with parallel surfaces. Instead, the figure of the lens—that is the manner in which the surfaces are fashioned—causes the refraction to become less towards the center of the lens, where it ceases, and the rays pass straight through the glass. Such lenses are made so that all the rays from the star meet at a point called the focus, where an inverted “image,” or complete picture, of the star is formed, to be magnified by the eyepiece. The fact that the image is inverted is of no disadvantage in astronomy, for most of the heavenly bodies that we examine can never be seen otherwise than with a telescope. In telescopes for terrestrial use the

inverted image is restored to its erect position by inserting additional lenses in the eyepiece.

We may regard the light entering a telescope as a bundle of parallel rays, the size of which depends on the diameter of the object glass. The lens acts like a funnel in a bottle placed on the lawn to collect rain, which it causes to converge through the neck into the bottle. The larger the mouth of the funnel, the more rain collected, and the sooner the bottle is filled. Similarly, the larger the object glass, the more rays of light will be collected. The effect of the object glass, then, is to converge the light rays to a focal point by refraction. The eye-

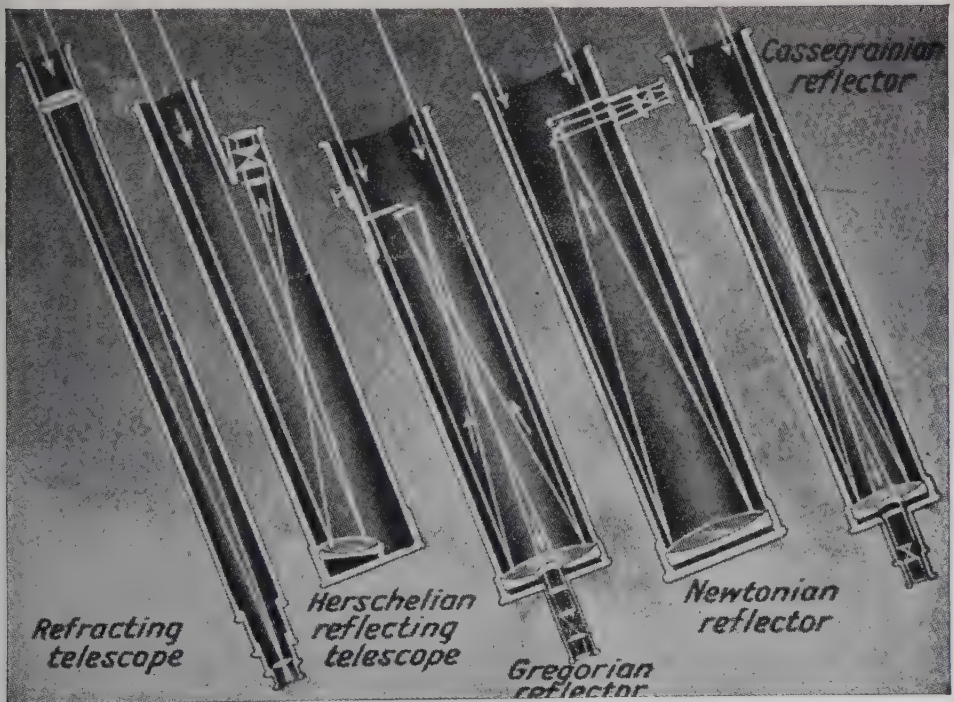


Fig. 26. The two kinds of telescopes. On the extreme left is a refractor; the others are reflectors. Reflecting telescopes are so called because in them the rays of light from an object are collected on a silvered mirror and reflected to a focus, where a magnifying eyepiece is placed

piece which magnifies the image formed by the rays, enables it to be examined with varying powers, according to the requirements of the observer, or depending on what the atmospheric conditions will allow. The arrangement is similar to that of the human eye for it also is a lens system that receives a bundle of parallel rays from a distant object and brings them into focus on the sensitive retina.

Sometimes people are surprised to find how much even a small telescope will show—say in the number of the stars.

TELESCOPE CONSTRUCTION

The explanation is not very difficult to find. As the diameter of the pupil of the eye is at the most one-third of an inch, a telescope with an object glass only one inch in diameter (equal to a good opera glass) will therefore collect no less than nine times the amount of light that normally enters the eye. To put it in another way—suppose there are two stars one of which is just perceptible to the unaided eye and the other sends only one-ninth the light of the first. Then the fainter star will become perceptible in a telescope with an object glass one inch in diameter.

After Galileo's death larger telescopes were made by different opticians, but as the sizes increased it was found that difficulties increased also. The chief trouble was that the objects seen through these instruments appeared to be surrounded with a fringe of colors, due to what is known as "chromatic aberration." This is caused by the difference in the refrangibility of different kinds of light from any object, the less easily refracted red rays being brought to a

focus farthest from the lens, while the violet rays, being more refrangible, are brought to a focus nearer the lens. The effect is to produce a series of differently-colored images of the object.

In these early telescopes, too, there was another defect, known as "spherical aberration," due to the rays of light that pass through the peripheral part of the lens being refracted in a manner different from that of those passing through the parts nearer the center. This results in a curved focal plane being formed instead of a flat one.

Huygens, Bianchini, and Cassini endeavored to overcome the difficulty of chromatic aberration by increasing the focal length of their telescopes, and in consequence these became very unwieldy, some reaching 120 feet in length. About the middle of the eighteenth century, however, Chester M. Hall discovered that chromatic aberration could be eliminated by using a combination of lenses in the object glass—a convex lens of crown glass and a concave lens of flint glass (Fig. 28). This type of telescope is called the "achromatic."

The discovery of the achromatic object glass has a peculiar interest in that Newton had expressed the opinion that nothing could be done to overcome the chromatic aberration of the single object glass in the telescopes of his day. Strangely enough, Hall, the discoverer of the achromatic, was indifferent to fame and profit and did not even make public his invention. It was left to John Dollond, an optician, to work out the principles involved in 1758. Even his work was ineffective for a time, however, for the British Government imposed a crushing duty on flint glass.

At that time flint glass of perfectly homogeneous quality could only be obtained in small pieces, and discs of even two or three inches were practically unobtainable. About 1784, P. L. Guinand, a Swiss artisan, commenced to experiment in its manufacture. After seven years of research, during which time he was reduced almost to poverty, he was able to produce discs of from four to six inches diameter. Later, after years of tedious work, he eventually turned out discs of 18 inches.

The secret of his process was of a mechanical rather than a chemical na-

lenses of some of the world's largest refracting telescopes, of which the largest is the 40-inch at the Yerkes Observatory situated near Lake Geneva, Wisconsin. The picture of this imposing telescope is seen in Fig. 28.

NEWTON'S REFLECTOR

When Newton decided that it was impossible to improve the refractor and eliminate the defects of the early instruments, he turned his attention to producing an alternative form of telescope, known as the reflector. Light is reflected from a body at an angle that is equal to the angle of

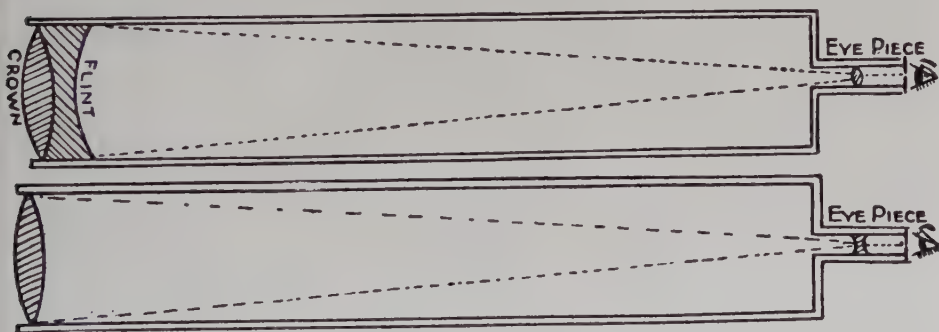


Fig. 27. (Top) The arrangement of the achromatic object glass: a convex lens of crown glass, and a concave lens of flint glass. (Bottom) Refracting telescope with single object glass as first used

ture, that is to say, it was a question more of the manipulation of the ingredients than of their quality or composition. After his death the secret passed to his son, and from him to G. Bontemps, a director of a large glassworks at Choisy-le-Roi. When revolutionary troubles arose in France in 1848, Bontemps fled to England and settled at Birmingham, where he entered into partnership with the Messrs. Chance, the famous glass workers, to whom he communicated the secret of the Guinand process. This firm subsequently made the

incidence, or that at which the ray strikes the reflecting body. The reflecting telescope depends for its power on a mirror with a paraboloidal surface that has the geometrical property of converting a beam of rays into a cone of reflected rays (Fig. 26). These rays converge at the focal point, forming, as it were, the opposite to a motorcar headlight or a searchlight, in which a point of light is converted into a broad beam of parallel rays, the width of which depends on the size of the reflector used.

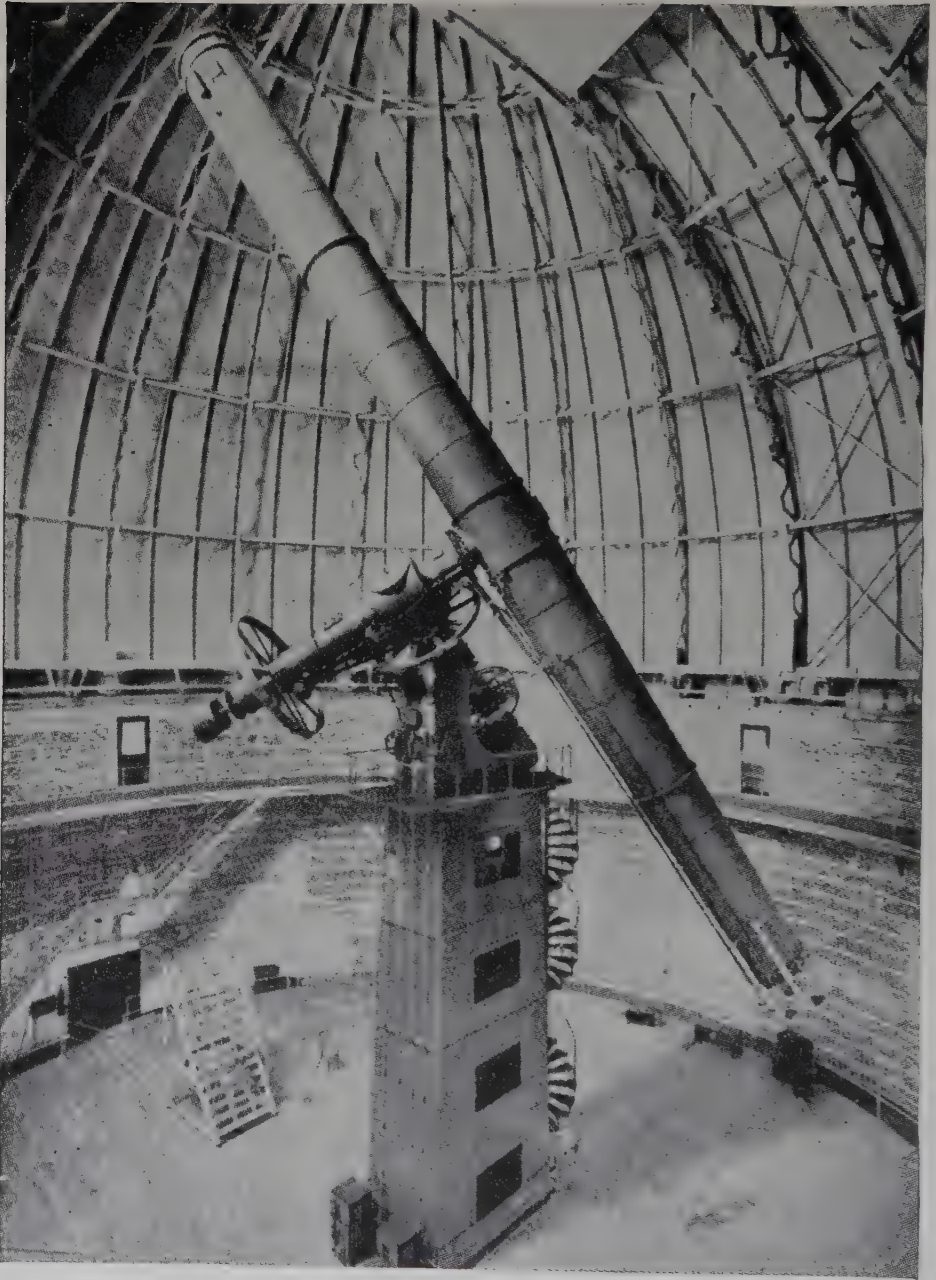


Fig. 28. The 40-inch refracting telescope at the Yerkes Observatory. To facilitate observation, the floor of the observatory rises and falls as required. It is operated by hydraulic power. The observatory is on Williams Bay, Lake Geneva, about 65 miles from Chicago

Normally the focal point from the mirror of a reflecting telescope is in the center of the open tube, at the bottom of which the mirror is mounted. This is obviously useless for observational purposes, so Newton introduced a small mirror with a plane surface, at a point slightly nearer the main mirror than the focal point. This is seen in the second telescope from the right in Fig. 26. This small mirror, or "flat," was placed at an angle of 45° to the axis of the large mirror and was held in position in the mouth of the tube by thin metal bars which offer a negligible obstruction to the passage of the rays entering the mouth of the tube on their way to the large mirror at the bottom. The flat therefore reflected the converged beam from the large mirror to a point at the side of the tube in which a hole was cut to permit the insertion of an eyepiece.

The mirror of the first telescope Newton constructed on this principle, in 1668, measured only one inch in diameter and was made of speculum metal, an alloy of tin and copper in the proportion of one to four. This gives a white glassy surface capable of taking a high polish. A great advance in the construction of reflecting telescopes was made by John Hadley, the inventor of the sextant, who, in 1723, presented the Royal Society with a Newton-type instrument with a mirror six inches in diameter. The performance of this comparatively small telescope surpassed that of the earlier type of reflector, even of one having a focal length as great as 123 feet.

HERSHEL'S DISCOVERIES

In the hands of Sir William Herschel the reflecting telescope

made possible many important discoveries, including that of Uranus. Herschel's largest telescope had a mirror 48 inches in diameter and a focus of 40 feet. We gain some idea of the difficulties in constructing instruments of this type when we learn that the total thickness to be abraded from the edge of this 48-inch speculum to convert it into a paraboloid is only $\frac{1}{21,333}$ inch. On this microscopic difference in form depends the definition and optical efficiency of the instrument. Accuracy has no limitations in the realm of science!

The largest reflecting telescope ever constructed with a speculum mirror was that erected in 1885 by the Earl of Rosse at Parsonstown, Eire. It had a mirror of six feet diameter and since nothing was known of the process by which Herschel achieved his results, his secret having died with him, Lord Rosse had to tackle the problem from the beginning. When completed the mirror weighed four tons, with a focal length of 54 feet, so that the question of mounting it presented almost as great a difficulty as the initial problem. The telescope did fine work, particularly in connection with the observation of distant nebulae. In this its enormous light-grasp was of great utility.

SILVERED GLASS MIRROR

In 1856 A. Steinheil suggested that glass discs might be used instead of speculum metal for the mirrors of reflecting telescopes. All the large reflecting telescopes made subsequently have had mirrors of glass, ground to the required curvature, with a thin film of silver deposited by a chemical process. The silver-glass mirror gives a particularly brilliant reflecting surface, reflecting more light than a

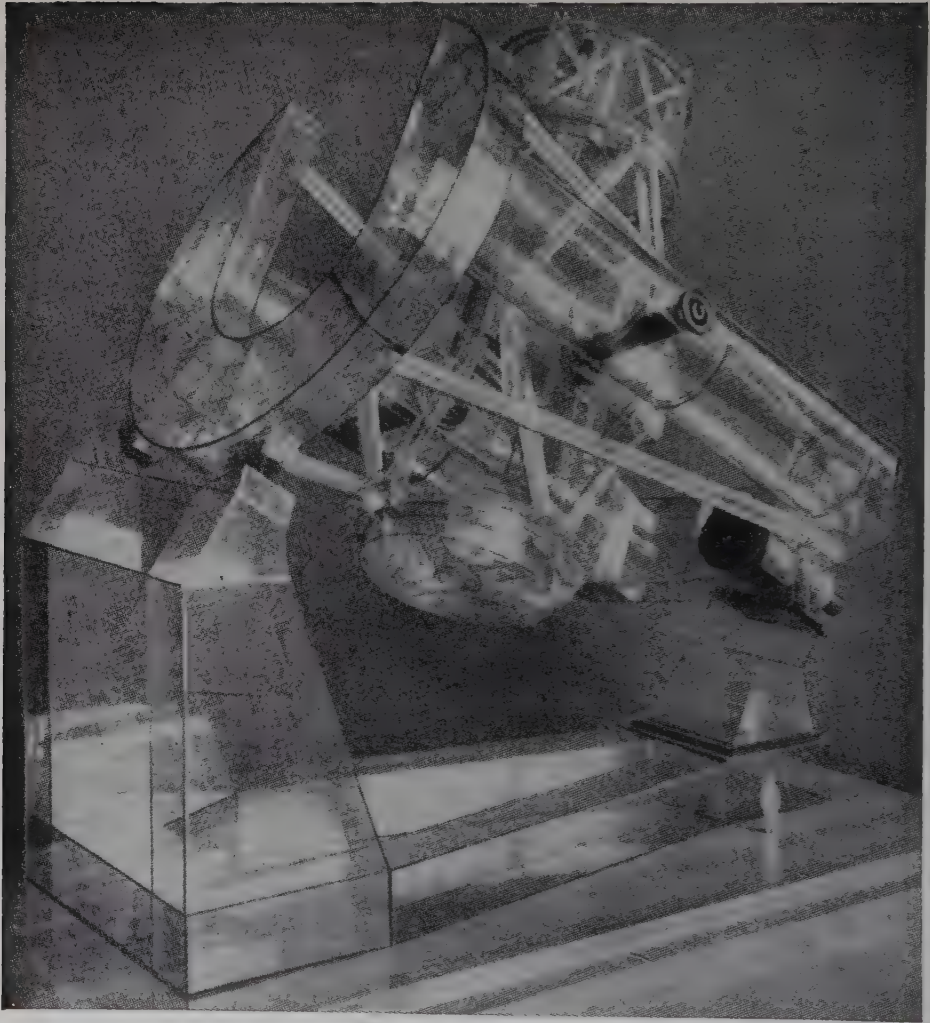


Fig. 29. An amazing celluloid model of the 200-inch telescope which is being erected on Mount Palomar. The model was made to scale so that the builders could see the position of every section. An idea of the instrument's dimensions is gained from the human dummy at its base

metallic mirror of the same area in the proportion of 16 to 9. The first large silver-on-glass reflector, made in 1879, had a diameter of 36 inches. This was followed by larger and larger telescopes, notably the 100 inch of Mount Wilson, at present the

largest in the world but soon to be surpassed by one of no less than 200 inch aperture.

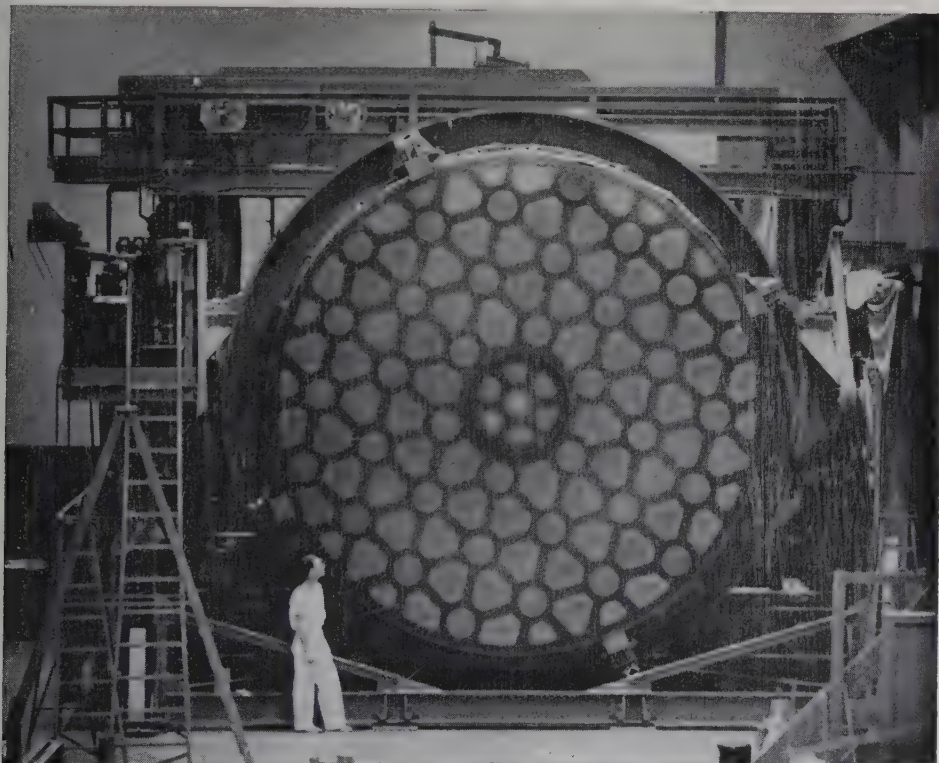
This extraordinary instrument (Fig. 29) is now being installed on Mount Palomar, a 5,700-ft. peak situated a hundred miles south of Los Angeles,

in California. It will be the largest telescope the world has known and will reveal things beyond the wildest dreams of astronomers of even twenty years ago.

Considered only as an engineering work, the construction of this reflecting telescope is an unparalleled achievement. Engineers today are able to build a towering skyscraper in a year, or a giant liner in two years. Yet the combined efforts of engineers and physicists have required no less than 12 years for the construction of this tremendous telescope, from which statement we are able to gather

something of the difficulties of the task that lay before them.

Two years of research work were necessary in connection with the casting of the giant disc of glass that forms the mirror, and during this time experimental mirrors of up to 120 inches in diameter were cast. The casting of the 200-inch mirror itself commenced in 1934, the glass being heated in a 30-foot furnace for three weeks and maintained at a temperature of $2,800^{\circ}\text{F}$. For eleven months the disc was annealed, the temperature being gradually decreased at the rate of 1.8°F . each day. This disc,



O. K. Harter

Fig. 30. The 200-inch grinding machine with the 200-inch mirror of the telescope to be erected on Mount Palomar. The grinding machine was constructed at the California Institute of Technology, where this picture was taken

which weighs 20 tons and is about 25 inches thick, is made of a special type of Pyrex low-expansion glass. Thus it is not so susceptible to temperature-changes as ordinary glass. The great slab was shipped in 1936 from the Corning Glass Works, in New York, where it was cast, to Pasadena, California, for grinding. It traveled in a 15-ton crate at the rate of 25 miles an hour, carried by a special train.

THE 200-INCH MIRROR

The grinding and polishing of the mirror, which is being carried on in an air-conditioned optical shop specially built for the purpose at Pasadena (Fig. 30), was begun in 1936 and will be completed in 1941. Although four tons of material have to be removed from the top, the reflecting surface must be accurate to

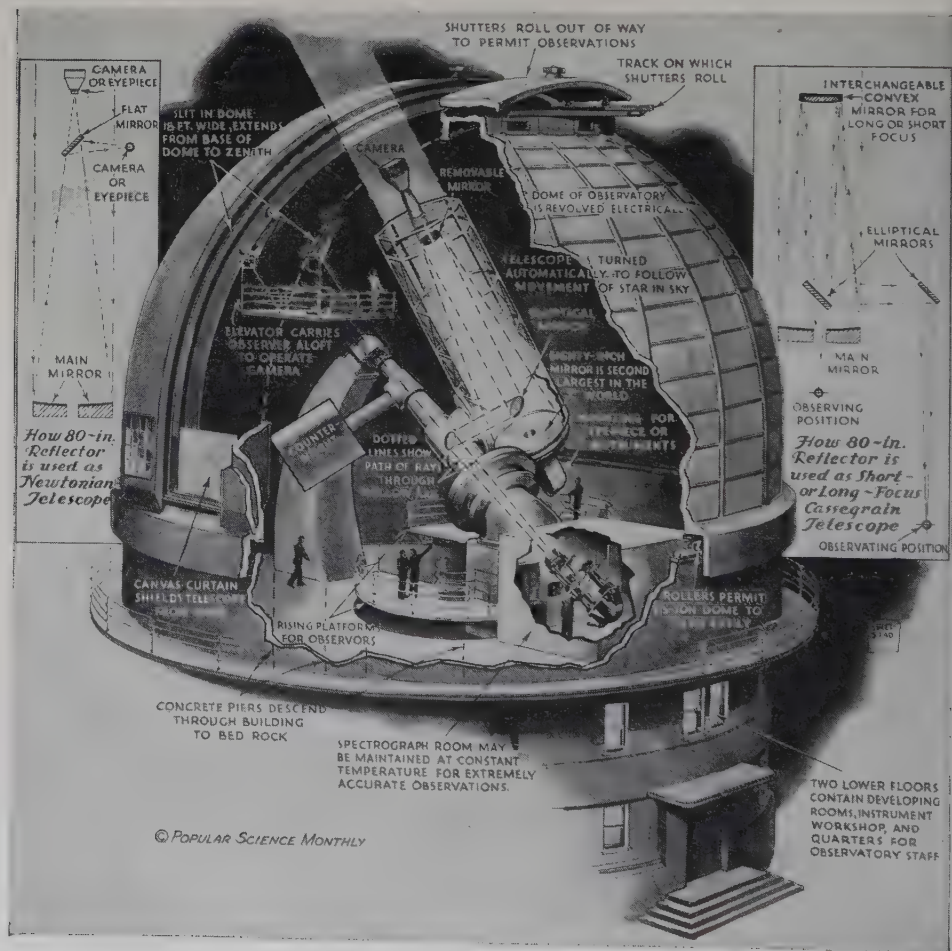


Fig. 31. A sectional view of McDonald Observatory in Mt. Locke, Texas, containing one of the largest telescopes in the world

two-millionths of an inch. When the grinding has been done and the correct curve achieved, a coating of vaporized aluminum will be deposited on the glass to give a mirror surface.

The mirror will be so heavy that a special arrangement of supports is to be fitted into the honeycomb-ribbed back. Despite its weight, the telescope will move with ease and precision at a touch from the observer, who will be able to "aim" it at will.

This giant "optick tube"—as Galileo called his first little telescope—will bring the moon to within a distance of approximately 25 miles. It would readily detect the light of a candle 10,000 miles away in space. Assuming a flat earth, or sea, if the great telescope could be erected in Liverpool and trained on New York it would be possible to tell whether a house had one or two stories, a discrimination that can be made with the naked eye at a distance of about a mile on a clear day.

USE OF THE SPECTROSCOPE

We have mentioned the fact that the light which a white hot solid radiates is made up of all wave lengths of the visible spectrum in addition to the longer wave lengths of the infrared region. When this light is passed through the prism of a spectroscope a continuous spectrum of colors from red to violet is obtained. On the other hand, when gases or vapors are heated until they become luminous, light of certain wave lengths only is emitted. What is more remarkable, these wave lengths are characteristic of the atoms of the elements of which the gas is composed. For example, if a discharge tube be filled with hydrogen gas at low pres-

sure and the gas excited to luminosity by an electrical discharge, the hydrogen atoms will emit a bluish-violet light. If this light is analyzed by the prism of a spectroscope, four bright lines of color corresponding to four characteristic wave lengths of light will appear—one red, one blue, and two violet. These lines are so characteristic of hydrogen atoms that they permit the identification of this gas by means of the spectroscope. Similarly, the spectrum of neon is easily recognized by red lines of great brilliancy and sodium vapor by a characteristic yellow line.

Spectroscopic analysis has been of great value to chemistry, for it permits of the identification of minute traces of elements and has led to the discovery of many new elements. The mechanism by which a given kind of atom emits its characteristic wave lengths of light has been an absorbing study to physicists and has led directly to our modern theories of the structure of the atom. In astronomy the telescope permits us to see objects which are invisible to the naked eye; but the spectroscope enables us to identify the materials of which they are made by analyzing the light received from them. Not only are we able to bring the stars into our laboratories and to see of what they are made; but we have been able to advance our knowledge of physics by discovering what is taking place in the stars where there exist conditions of temperature and of pressure unduplicated in any laboratory.

If the spectroscope is used to analyze the light of a certain star and it is found that the resulting spectrum is identical with that of the element sodium—to use an imaginary example—then we should be justified in com-

ing to the conclusion that the particular star examined was nothing less than a flaming ball of sodium. As each element in vapor form has its characteristic set of lines in the spectrum, and as these lines have been identified by comparison with the respective elements in laboratory experiments, it is not difficult to understand how we can identify the corresponding elements in the spectrum of a star or other heavenly body.

THE SOLAR SPECTRUM

An examination of the solar spectrum shows us that many of the chemical elements found on the earth exist in the sun—calcium, carbon, chromium, copper, hydrogen, iron, lead, magnesium, nickel, potassium, silver, sodium, tin, and zinc, to mention only a few. After all, this is only what we should expect, for, as we have seen, the earth was formed from the same cloud of gas, or nebula, as the sun.

In this connection it is interesting to remark that an orange-yellow light seen (by P. J. C. Janssen, a French astronomer) in the solar spectrum during an eclipse in 1868, and thought at the time to be the characteristic lines of sodium, was later found to originate in an unknown element, which was named "helium." In 1894, some 26 years after its discovery in the solar spectrum, Sir William Ramsay, when spectroscopically examining a gas he had obtained from the rare mineral cleveite, found the same orange-yellow ray, showing that helium exists also on the earth. Next to hydrogen, helium is the lightest gas and since it is non-inflammable it is specially valuable and safe for use in dirigibles and balloons. In the United States, and also in Canada, supplies of helium are obtained from a natural gas. The first airship to use helium in aerial navigation was the "C7" of the U. S. Navy.

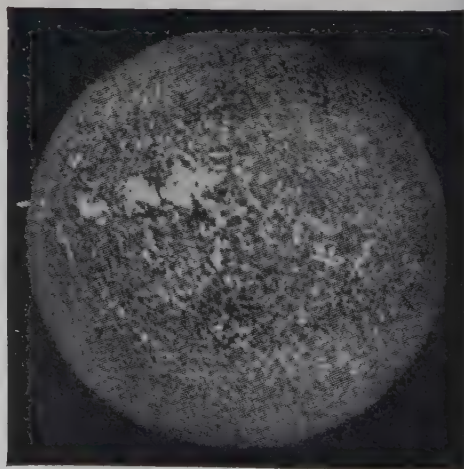
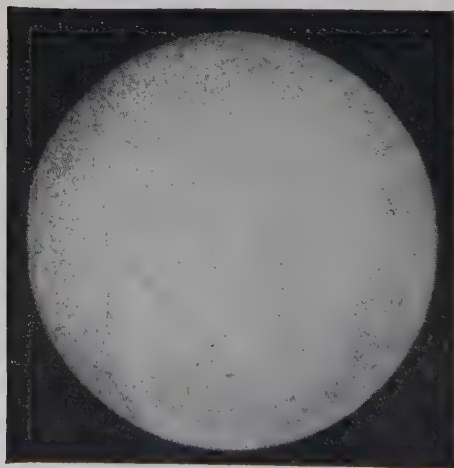


Fig. 32. (Left) The sun photographed through a telescope, and (right) through the spectroheliograph, with the monochromatic light of hydrogen. In the latter photograph great masses of this glowing gas are seen surrounding the sunspots. Without the spectroheliograph, the presence of these hydrogen areas could not have been ascertained in this way

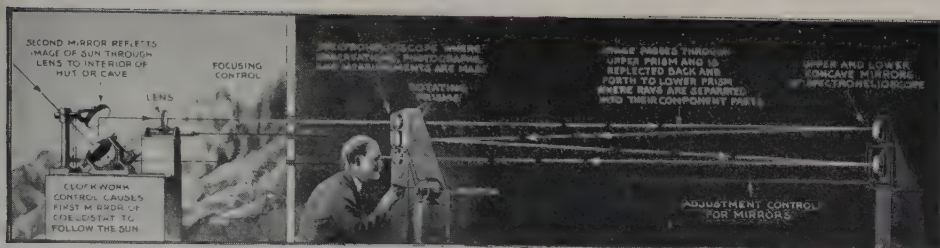
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Fig. 33. How the spectroheliograph enables us to photograph the sun by monochromatic light. The spectroscope analyzes the light from a star, and shows the characteristic lines of sodium. It is identified as such by comparison with light from a lantern in the flame of which sodium is being burned. The lines of sodium are yellow in color

A development of the spectroscope is the spectroheliograph (Fig. 33) by means of which the sun may be photographed only by the monochromatic light of certain gases, such as calcium or hydrogen. To express it another way, a photograph of the sun taken by the light of hydrogen alone will show only hydrogen; taken by the light of calcium, it shows only calcium. Such an arrangement is of the greatest value in solar physics.

WHAT THE SPECTRUM TELLS US

Moreover, further details in the spectrum enable us to determine several other facts about the body from which the spectrum comes. Without going too deeply into the matter, we may say that it is possible to determine whether the body being examined is in a solid, liquid, or gaseous state, and whether under compression. We can also tell when light from a solid or liquid body passes through a gas, in which case the same wave lengths of light are absorbed by the gas from the continuous spectrum of the hot solid as are normally emitted by the gas when luminous.

Another important detail is that the spectroscope can tell us whether a

star is moving away from, or towards, the sun—it even enables us to calculate the approximate speed of recession or approach of these stars. To explain how this can be done we refer back to that part of our section on sound in which we mentioned the fact that the pitch of a sound increases if the observer or the source of the sound is in relative motion. We mentioned, as an example, the increase in pitch of the whistle of an approaching express train. The difference in pitch is readily recognizable in the case of sound, since its speed of travel is relatively slow.

In 1842, Christian Doppler, an Austrian physicist, stated that the same principle would apply in the case of light waves, the velocity of which is nearly a million times greater than that of sound waves. As the frequency of light waves determines the color or tone—as that of sound determines the pitch or tone—Doppler suggested that the color of a luminous gas would be changed by movements of approach or recession.

The principle of the Doppler effect is briefly this. If we are traveling towards a source of light that is emitting light waves of a particular wave

length in our direction, we meet more light waves per second than would be the case if we were stationary. The result is that the wave lengths of the light are shortened. If we are receding from the source of light the wave lengths are increased. A standard of reference for the lines in the spectrum of a star is obtained in the laboratory and is placed alongside the stellar spectrum. If the star is moving towards us, every wave length of the light received from the star will appear shorter than it would if the star had no motion towards us. The effect is that the whole spectrum is moved slightly, the rays at one end being shifted into invisibility while the rays at the opposite end are rendered visible, or vice versa as the case may be.

In the spectrum of a star that is moving towards us, the lines are displaced towards the shorter wave length—that is towards the violet end of the spectrum. On the other hand, if the star is receding the displacement is towards the red end of the spectrum. By carefully measuring the amount of such displacement, the velocity of the star's approach or recession can be determined. To mention only two examples, the Doppler effect shows that the bright star Arcturus is approaching us at over 40 miles a second, and that Aldebaran is receding from us at 45 miles a second.

Such is the extreme delicacy of modern scientific observations, that the spectroscope will not only show in the heavens that a nebula is receding from us at a speed of 15,000 miles a second—about a million times the speed of an express train—but it will also detect in the laboratory the presence of $\frac{1}{3,000,000,000}$ part of an ounce of lithium.

Let us now see something at the other end of the scale, leaving the telescope that enables us to explore the heavens and the depths of space, and turn our attention to the microscope by which we are able to explore the mysteries of the unseen world around us. The microscope also depends on the refraction of light, and it seems little short of marvelous that we can use this principle equally well for learning about the greatest and the smallest objects.

INVENTION OF THE MICROSCOPE

The actual date of the invention and the name of the inventor of the microscope is not known. As early as the first century, Seneca—the tutor of the infamous Roman Emperor Nero—noticed that if a globe of glass is filled with water, writing seen through it appeared larger than it actually was. The first mention of lenses for magnifying purposes appears to have been made in 1276, when Roger Bacon showed how crystal lenses could be used to make objects appear larger. "With these lenses," he wrote, "an instrument could be made, useful to old men and to those whose sight is weakened, for by means of it they would be able to see letters, however small they are, made large and clear." It is believed that the first microscope was made at some date between 1590 and 1607 and that credit for the invention must be given to one of three spectacle makers of Middleburg, Holland—Hans Janssen; his son Zacharias; or Hans Lippershey, whose work in connection with the telescope we have already mentioned.

The man who made the best use of the microscope in these early days was Anthony van Leeuwenhoek, who was born in the middle of the seven-

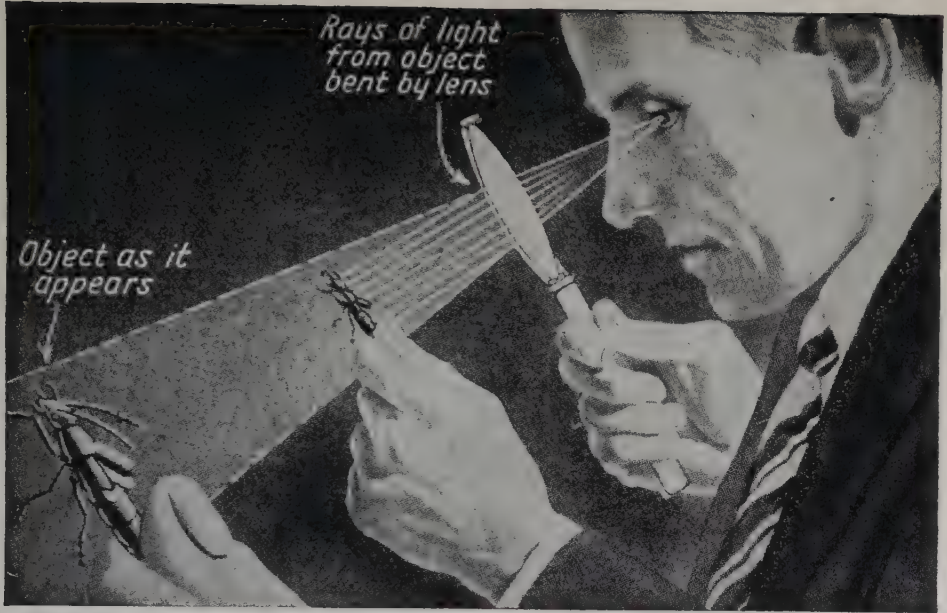


Fig. 34. How a simple magnifying glass increases the apparent size of an object. A microscope such as this magnifies an object from 10 to 20 times its normal size

teenth century near Delft, Holland. He was a humble draper, but science was his hobby and his discoveries opened up a new world with infinite boundaries and undreamed-of mysteries. By a fortunate accident he came into possession of a strange instrument consisting of a long tube with a lens at each end—one of the early microscopes. With it he examined everything he could lay his hands on—nothing was too commonplace for his attention. He found life almost everywhere—in dust, earth, and sea water he found myriads of little animals—or *animalculae*, as he called them—and everything seemed to be teeming with life. Even blood was no longer a rich red fluid but a yellow liquid in which floated coin-like discs. Flesh was not merely pulp but was composed of a mosaic of countless millions of minute round

bodies that we now call “cells.” He saw that insects and worms were not merely moulded masses of a structureless substance but were marvels of beauty and perfection. His neighbors thought he was crazy, but we know today that the work of Leeuwenhoek paved the way for Pasteur and Lister. The great benefits they conferred on mankind might never have come about and microbes and bacteria might have continued their harmful activities unchecked by modern science. That we have been able to understand the causes of the diseases they produce, and also the good uses to which they can be put—as in fermentation—is due to the refrangibility of light by glass.

HOW MICROSCOPES MAGNIFY

How is it that a microscope magnifies small objects? To explain this we

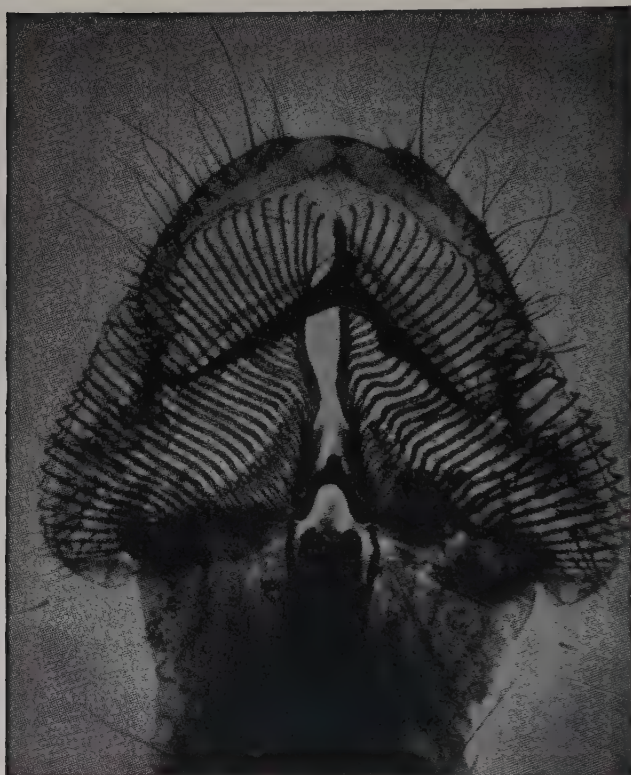


Fig. 35. Microscopic photograph of a fly's proboscis. With a powerful microscope objects that measure no more than $\frac{1}{250,000}$ of an inch in diameter can be made visible to the human eye or to a camera

must realize that there is a limit to the nearness at which an object can be focused by the eye. Generally this "limit of distinct vision" is reached when objects are about 10 inches from the eye. What happens is that a microscope assists the lens of the eye to focus clearly objects that are closer to the eye than the limit of distinct vision.

An ordinary reading glass is, in effect, a simple microscope. It consists of a single lens that is brought to bear on the object to be examined. Rays from the object are refracted by

the lens to a focus at the observer's eye, as will be clear from Fig. 34. By a simple microscope such as this an object may be magnified from 10 to 20 times, and even this comparatively low magnification reveals many details that cannot be seen with the naked eye. In this form simple microscopes of one lens have many uses as magnifiers to assist in the dissection of animal or vegetable tissues, and for other such simple requirements. Lenses of this kind could be made to give a higher magnifying power, but in such a case the object to be examined would have to be placed very close to the lens and the eye would have to be equally close on the other side, and this would be inconvenient.

Then again there would be the same serious difficulty of chromatic and spherical aberration that occurred in the early telescopes before the achromatic lens.

To overcome these defects the compound microscope was introduced. In this instrument the essential features are—as its name suggests—a series of compound lenses of crown and flint glass, exactly as is used in the achromatic telescope.

The elimination of both chromatic and spherical aberration is effected in the objective, or object lens, as it is

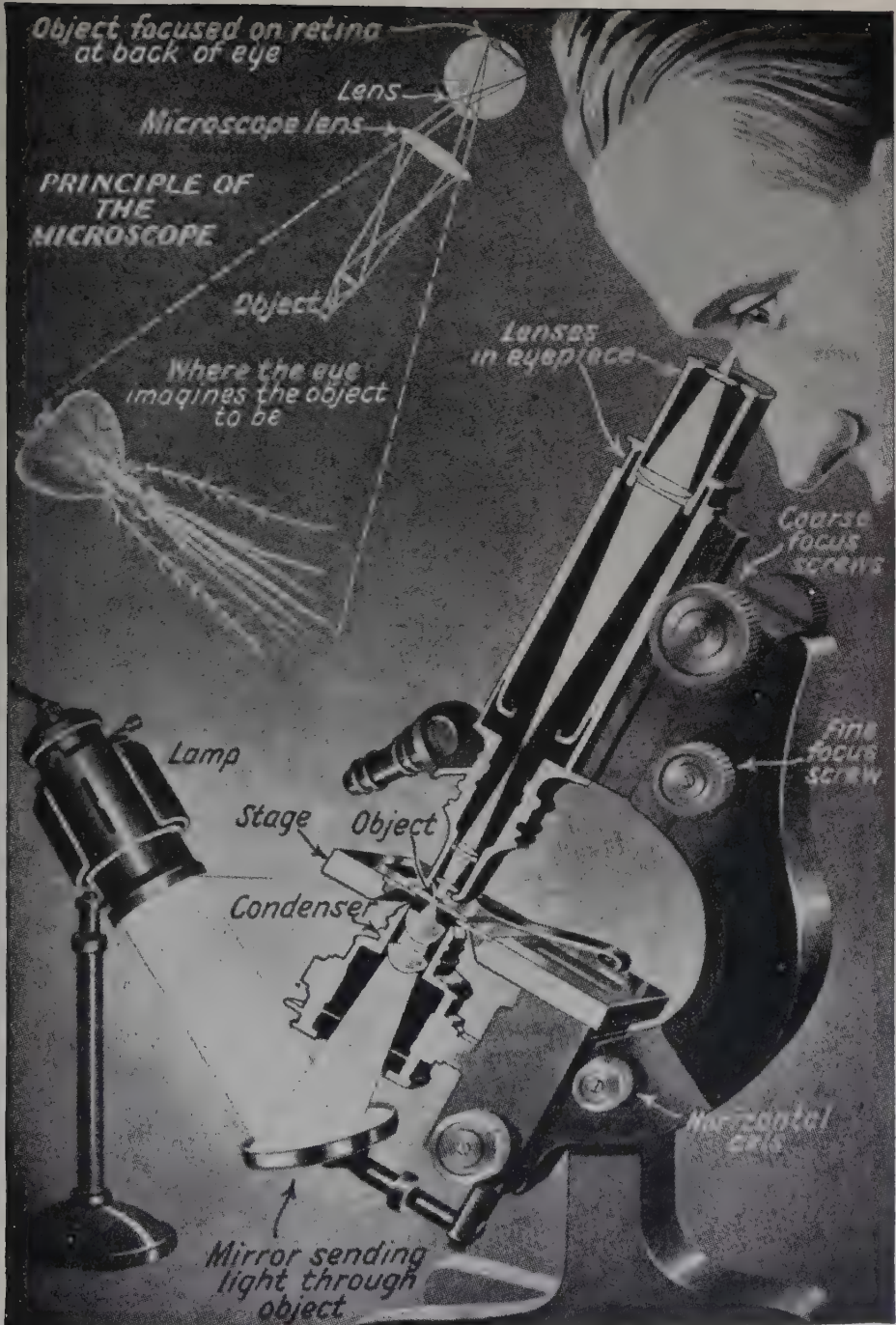


Fig. 36. The workings of a compound microscope

in the telescope. The concave lens of flint glass, having a greater dispersive power, allows two colors to combine into light that is approximately white, so that there may be a combination of yellow and green rays at one point. More than this the combination could not do, however, and the result is that the remaining uncorrected colors form what is called the "secondary spectrum." Subsequently, this, too, was eliminated by the use of special optical glass of different refractive indices, introduced as the result of the researches of Ernst Abbé, who worked in conjunction with Carl Zeiss and Schott at Jen. (Abbé was first a director and later after the death of Zeiss, sole owner of the great Zeiss optical works.) Those combinations of lenses that remove the secondary spectrum and correct spherical aberration are known as apochromatic objectives, or apochromats.

THE COMPOUND MICROSCOPE

In the compound microscope the objective forms an enlarged image of the object, and this is further magnified by the eyepiece as though it were a real object being examined with a magnifying glass. Each of the lenses

of the objective and the eyepiece may be compounded—that is to say, they may be made up of more than one lens of flint and crown glass. For example, objectives are generally made up of two or three achromatic lenses.

The objective is placed at one end of a tube and the eyepiece at the other, the tube being raised or lowered by a screw or rack-and-pinion movement so that the objective may be brought to the required distance from the object under examination (Fig. 36). The whole is mounted on a rigid stand that also supports a stage on which the object is placed. A hole in the stage allows light to pass, the light being concentrated from a mirror by a sub-stage condenser.

With a powerful microscope objects that measure not more than $\frac{1}{250,000}$ of an inch are clearly revealed to the human eye or photographic plate. A drop of water from a pond may be so magnified as to become a world in itself, with diverse specimens of minute animal and vegetable life, the construction and origin of which present problems of such tremendous difficulty that even today they remain numbered among the mysteries of science.

CHAPTER 15

MAGNETISM AND ELECTRICITY

EVERYONE is familiar with the magnet. A small example of the horseshoe variety can be bought at any department store for a nickel. Even one of these toys will teach us much about the great principles on which many ingenious devices are based and on which we depend for many things in our everyday life, from the streetcar and the telephone to electric light and modern television machines.

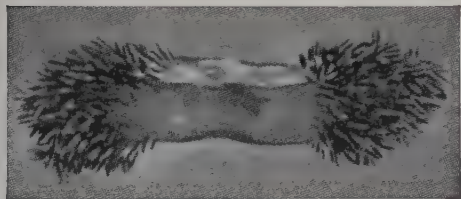


Fig. 1. If a piece of magnetite be dipped into a box of iron filings, the filings cling to its extremities, leaving the middle bare

Natural magnets—so called because they possess magnetism when taken from the earth—were familiar to the ancients in the form of lead-colored stones, now known as oxide of iron or magnetite. The Chinese discovered that if a piece of this ore is suspended so as to hang freely, it will assume a position pointing north and south. From this fact they called it the “load-stone,” meaning “leading stone,” because it led them in a desired direction.

Magnetite was first found in the province of Magnesia, in Asia Minor, and from this is derived the name “magnet.” The ore was found later in other places—particularly in Sweden, Arkansas, and Spain—in irregular crys-

talline fragments and occasionally in thick beds.

If a piece of this ore is dipped into a box containing iron filings, it will be found that the filings cling in greatest numbers to the ends of the loadstone, while the center part is without filings (Fig. 1). This shows that the attractive force is greater at the two ends than at others, and these points of greatest attraction are called the “poles.”

An artificial magnet may be made from a bar of iron or steel by stroking it with another magnet (Fig. 2). For instance, it is quite a simple matter to make a needle or a knitting needle into a magnet by stroking it in this way, provided the strokes are always in the same direction—either left to right or right to left. Because iron does not retain its magnetism for any length of time, steel which keeps its magnetism is used when a permanent magnet is required.

A magnet may be either in the form of a straight bar or shaped as a horse-



Fig. 2. Magnetizing a needle by stroking it in one direction with a permanent magnet



Fig. 3. A horseshoe type magnet and its keeper, which is placed across the ends of the poles to assist in preventing the loss of magnetism when the magnet is not in use

shoe—which is simply a straight bar bent; and these are the commonest forms (Fig. 3). Of the two, the horseshoe type is the stronger and will lift about three times as much weight as a bar magnet. The reason for this is that the attractive power of the two poles is combined, owing to their being nearer together. When not in use, a small piece of metal, called a “keeper,” is kept across the poles of a horseshoe magnet to help to preserve its strength. Magnets may also be in the form of a continuous ring, or a disc of iron or steel, but neither of these shapes are often seen, being used in the laboratory.

Artificial magnets also have poles. In a bar magnet the poles are at each end of the bar and here are the points

at which the attraction is greatest, there being practically no attraction at the center (Fig. 4). The same remarks apply to natural magnets.

If a magnet or a magnetized needle is allowed to swing freely, as when suspended by a strand of silk or a hair, or placed so as to be free to rotate on a point, it will turn towards the north pole of the earth (Fig. 5). This property is the basis of the mariner's compass. The Chinese used the magnetic compass nearly 3,000 years ago, and it would seem that the knowledge of the compass spread from them to the Arabs, who in turn introduced it into Europe. Exactly when this was we do not know, but a primitive form of compass was used by European sailors in the twelfth century. It consisted of an iron needle that had been stroked with a load-stone. It was placed on a pivot, or floated on water, so that it could turn freely, and in this manner was able to come to rest in a position that was approximately north and south.

THE MARINER'S COMPASS

The modern form of the mariner's compass is due to the work of Lord Kelvin, who perfected it towards the latter half of the last century. He re-



Fig. 4. Bar magnet with poles at ends

placed the long, heavy needle of the earlier compasses with the present short needle. In the center of the card is an aluminum ring carrying a highly polished sapphire to reduce friction. The needle itself consists of eight thin magnets—steel strips measuring from two to three and one-quarter inches in length and strung together by fine silk threads. These in turn are attached to 32 silk threads that extend radially from the aluminum ring to the center disc that pivots on the sapphire.

The first study of magnetism was carried out by Dr. William Gilbert, who made the subject his lifework. In 1600 he published his researches in *De Magnete*, the first great work on physical science to be published in England. Gilbert explained not only why a compass needle took a definite direction but also the “magnetic dip,” as it is called, a matter that had been noticed before Gilbert’s

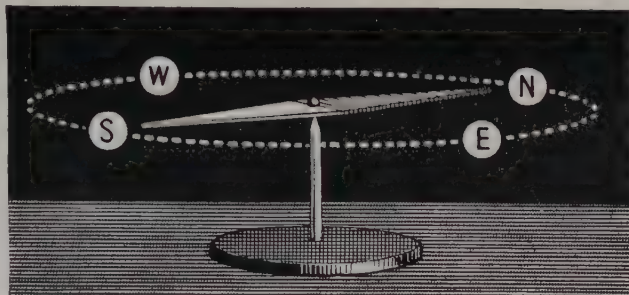


Fig. 5. When a magnetized needle is allowed to swing freely on a pivot, it will always come to rest in a north-and-south position

time, and to which we shall refer later.

If two magnets are hung side by side it will be seen that the two south poles repel each other, whereas if the north pole of one magnet is placed near the south pole of the other, they attract each other. This is in accordance with the well-known law of polarity that “like poles repel and unlike poles attract each other.”

Every magnet has two poles. This can easily be proved by magnetizing a bar and testing for polarity with another magnet as described above. Now, if we break the bar in half we do not find that we have one magnet

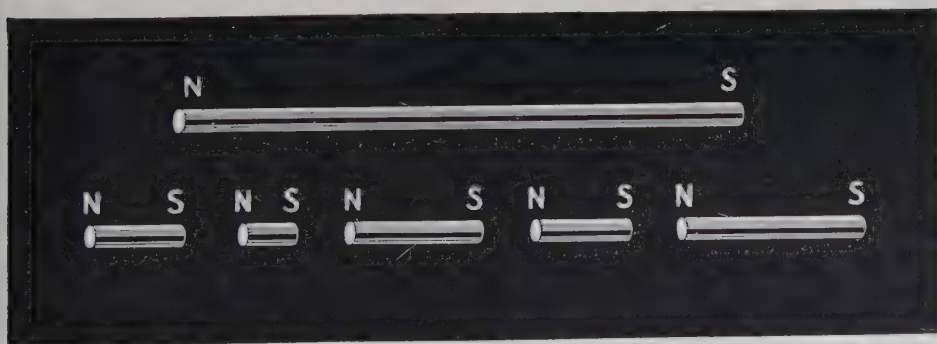


Fig. 6. If a magnet is broken into small pieces, its north pole remains “north,” but a new south pole is developed. If broken into smaller pieces, the poles are again distributed as before. The explanation of the magnetic principle involved is found in text on this page



Fig. 7. Diagram showing the positions of the earth's magnetic poles and magnetic equator, in relation to the geographical poles and the geographical equator

with north polarity and one with south polarity. Instead we have two smaller magnets, each with a north and south pole (Fig. 6). No matter how many times we repeat the process and subdivide the magnet—even if ground to powder—the result is always to produce smaller and smaller magnets, each complete with its north and south pole.

TWO MAGNETIC POLES

As we have seen, there are two kinds of magnetism, or two kinds of magnetic poles that attract and repel each other. One pole tends to swing towards the earth's north pole and the other to the south pole. Now, the earth itself possesses the property of a huge magnet having two magnetic poles. It is because of this that the magnetized needle of the compass

points to the north, for the magnetic pole of the earth attracts the dissimilar pole exactly as in the case of another magnet.

The geographic poles are the extremes of an imaginary line passing through the center of gravity of the earth and about which it revolves. The poles are therefore symmetrically situated with regard to the equator. On the other hand, the magnetic equator does not coincide with the geographical equator (Fig. 7) nor do the magnetic poles coincide with the geographic poles. One magnetic pole—that in the northern hemisphere—is 1,400 miles away from the north geographic pole. It was located in 1831 by Captain James Ross as being in King William Land, Canada, at a point $70^{\circ} 5' N.$ latitude and $96^{\circ} 43' W.$ longitude.

The position of the south magnetic pole was also first located by Ross. It was more closely determined by Shackleton's 1909 expedition to the Antarctic, which placed it at $72^{\circ} 25' S.$ latitude, and $155^{\circ} 16' E.$ longitude.

It is obvious that as a compass needle points in the direction of the magnetic pole, it does not point actually to the geographic pole. Clearly, the deviation from the true north of a compass in the northern hemisphere will become more pronounced as the compass is moved further north. Because of this fact allowance has to be made at any particular place for this "angle of declination," as it is called, so that an exact indication may be obtained as to how far away from true geographic north the compass needle is pointing. The values of the declination of the magnetic needle at different places are known and are shown on the charts, or magnetic maps, to which reference is always



Fig. 8. The new non-magnetic research ship "Research," which was constructed by the British Admiralty and launched in 1939. War halted her investigations

made when steering ships by the magnetic compass.

MAGNETIC STORMS

Although these allowances are fixed and regular, there are numerous magnetic disturbances of a non-periodic character. Some are pulsations lasting only for a few seconds or a few minutes, others are of a very irregular type. Large disturbances, known as magnetic storms, have their origin in the sun and are associated with displays of the aurora in the polar regions and with interruptions to telegraphic communications. They are probably due to the occurrence of electric currents generated in the earth's crust. These magnetic storms

vary over the eleven-year period of the sunspot cycle to which we have already referred, and they are more frequent and of greater intensity when sunspots are most numerous. In these years, too, the magnetic declination and inclination show decided changes.

There are observatories all over the world engaged in the study of magnetic phenomena, but as four-fifths of the surface of the earth consist of water, where observation is equally important, special research vessels are used for ocean study. A new floating observatory, "Research" was launched in 1939 on a quiet reach of the River Dart in Devon (Fig. 8). She replaced the Carnegie Institute research ship

which was destroyed by fire at Apia, Samoa, in 1929. The vessel is of special design throughout, particularly in regard to the fittings. The auxiliary machinery consists of three diesel engines for two dynamos, a refrigerator, and an air compressor, and aboard are laboratories or workshops, dark rooms, offices, and record rooms. Although the vessel cruises mostly under sail, she is fitted with an auxiliary heavy-oil motor. Her displacement is 850 tons, and she carries enough fuel to give her a cruising radius of 2,000

and even the cooking equipment must have no steel or iron in its composition. The ballast is of lead. There is accommodation for 22 petty officers and men, six officer-scientists, and four scientists.

The "Research" was scheduled to begin a long voyage to the South Indian Ocean shortly after she was launched. The scientific information which was to be collected would have been at the disposal of all nations. War brought an end to these fruitful endeavors.

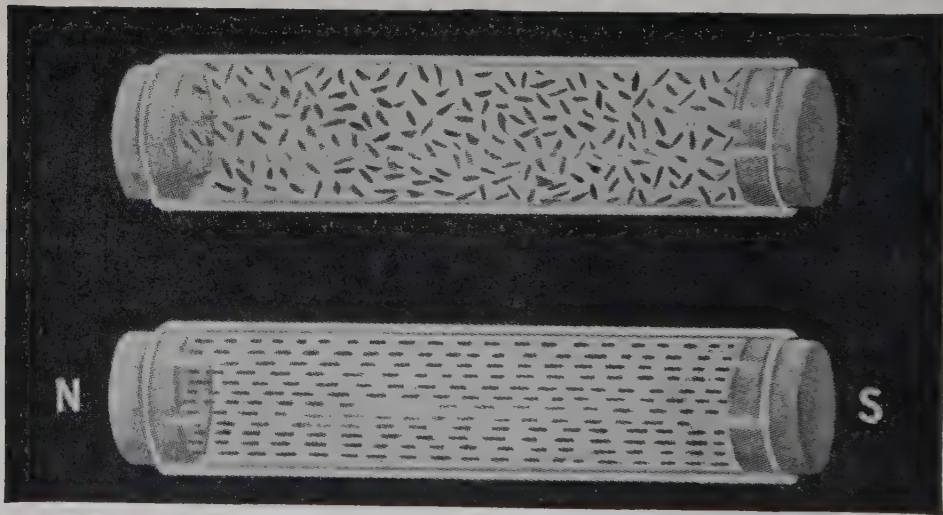


Fig. 9. An experiment to illustrate the atomic theory of magnetism. When a tube of iron filings (above) is magnetized, the filings all arrange themselves in the same direction (below)

miles at a speed of six knots. All the machinery and fittings are made of special non-magnetic alloys. Steel and iron, the chief building materials for ships, are rigidly banned, and members of the crew are not even allowed to carry a steel penknife. The hull is made of teak, with the framework, girders and fittings of bronze and other non-magnetic alloys. Anchor, cables, and all the bolts are of bronze,

MAGNETIC ATTRACTION

In addition to pointing in a north-and-south direction when swinging freely a magnet has the property of attracting certain metals. Not all metals are magnetic, however, some being attracted more than others. Steel and iron are the most easily attracted, whereas nickel, cobalt, and chromium are attracted very feebly.

Copper, lead, gold, and platinum are non-magnetic and cannot be made into magnets. Although some metals may be magnetized but do not retain their magnetism permanently, others retain their magnetism indefinitely and are known as permanent magnets.

Exactly how a magnet attracts metals cannot be stated—it is another of the mysteries of science. A very probable explanation, however, is provided by the atomic theory. We have seen already that all matter is made up of atoms—a steel bar is a mass of particles each of which is a tiny magnet with its north and south poles. In unmagnetized steel these atomic magnets are arranged in a haphazard fashion in the bar so that the mutual attraction and repulsion of their north and south poles cancel each other out, as it were. When the bar is magnetized, however, the atoms are rearranged in an orderly manner. They turn on their axes and tend to assume positions in which they are parallel to one another, with their north poles all pointing in the same direction.

The change in position of the iron atoms when a steel bar is magnetized cannot, of course, be seen, but we can demonstrate the idea by a simple experiment. A small glass tube is filled with iron filings, and corked at each end (Fig. 9). A freely-suspended unmagnetized needle is then brought near the tube to show that the tube has no marked attraction or repulsion at either end. If we now gently stroke the outside of the tube of filings with a magnet, repeating the process about a dozen times, and moving the magnet always in the same direction—being careful not to shake the tube—we find the filings arrange themselves in an orderly manner (Fig. 9). On

testing again with the unmagnetized needle, we now find that one end of the tube definitely attracts it. If we shake the tube, causing the filings to intermingle, we at once destroy the magnetism.

According to the atomic theory of magnetism, therefore, the atoms of unmagnetized steel or iron in a bar are irregularly disposed. When the bar is magnetized they are moved on their axes and arranged in a regular manner. When they are completely moved in this way the material is said to be “saturated,” and in this condition it cannot be further magnetized no matter how strong a force is employed.

WROUGHT-IRON MAGNETS

Wrought, or soft, iron is commercial iron in its purest form, whereas steel contains impurities—notably carbon—which impart certain desirable properties. Permanent magnets are made of steel, since the iron atoms in steel retain their magnetic alignment almost indefinitely.

On the other hand, when made into a temporary magnet by passing an electric current around it, soft iron has a greater attractive power than steel when current is flowing. Steel, however, has greater attractive powers when the current is switched off. Actually, when the current is switched off the wrought iron does remain magnetized very slightly, and this effect is known as “residual magnetism” as against the “retentivity” of the power of steel to retain magnetism. Residual magnetism is of great importance in operating electric generators, for their self-exciting properties depend on this factor.

The magnetic field around a magnet cannot be perceived by our senses

but its existence can be demonstrated by the effects it causes, as with iron filings. By sprinkling these on a sheet of paper or thin card, we can trace out the direction of this field and its distribution in the space. By sprinkling filings evenly on a card and placing a magnet underneath we see that the filings at once take up definite positions when the card is gently tapped (Figs. 11-13). As they are not distributed evenly over the magnet, it is clear that the magnetic force is not the same at all distances, but decreases according to the distance from the magnet. In these experiments we must remember that although the fil-

ings on the card show us the action of the magnetic force on a plane surface only, the force acts in all directions from the magnet.

The directions of the magnetic force from a magnet can be ascertained easily by means of a freely swinging needle, such as that of a compass. If a bar magnet is placed on the table and the needle moved around it from pole to pole, we see that it inclines at an angle that increases as the poles are approached and follows a continuous curve (Fig. 14). By noticing the inclination of the needle it becomes clear that the magnetic force has a definite direction at every point.

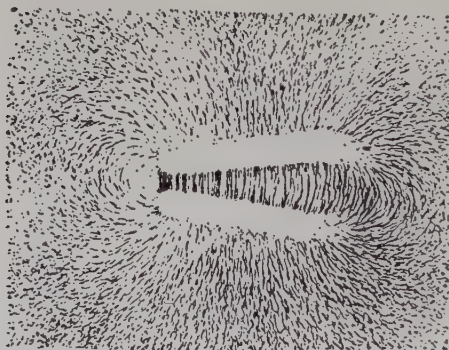


Fig. 10

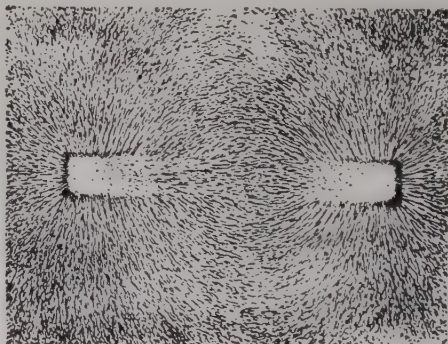


Fig. 11

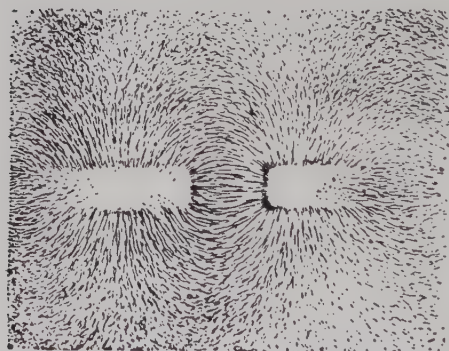


Fig. 12

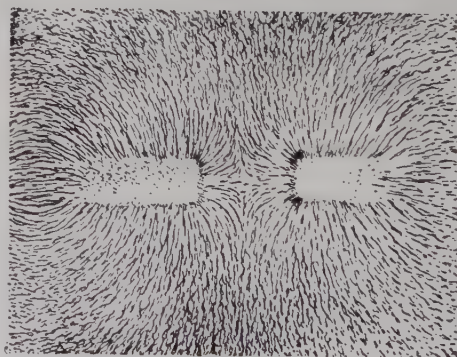


Fig. 13

Figs. 10-13. Lines of force traced in iron filings on paper by variously arranged magnets. Fig. 10. Horseshoe magnet. Fig. 11. Bar magnet. Fig. 12. Opposite poles of two bar magnets. Fig. 13. Similar poles of two bar magnets. Note that unlike poles attract and like poles repel.

The lines on which it acts are called *magnetic lines of force*. These lines of force stream away from each pole of the magnet, those from the north pole passing in curved lines to the south pole, completing the circuit back to the north pole through the magnet itself. Every line has a complete circuit, and it is for this reason that it is impossible to have a magnet with one pole.

HOW LINES OF FORCE BEHAVE

It is interesting to notice, too, that each magnetic line completes its circuit independently of the others and never cuts, crosses, or merges with another line. The lines are much more numerous where they leave the magnet at the north pole and where they re-enter at the south pole. This is due to the fact that steel is a better conductor of these lines of force than the surrounding medium, hence the lines of force are concentrated in the magnet and crowd together at the poles.

These lines of force in a magnet constitute the principle behind many electrical measuring instruments and electrical devices used in every day life. Such instruments rely on the fact that the magnetic lines of force always take the path of least resistance. If a piece of iron is suspended so that it is free to move in a magnetic field, it will tend to take up a position in which the greatest number of the lines of force are accommodated through itself. Should the moving body itself be a magnet, it will move in the same direction as those lines of the field in which it is mounted.

A sheet of wood or glass will not alter the deflection of a needle if placed between it and a magnet—in fact, there is no known material that will insulate a body from a magnetic



Fig. 14. How the magnetic lines of force which surround a bar magnet may be plotted by means of a small pocket compass

field. Wrought iron will serve as a screen, however, conducting the lines of force away from a region. For this reason delicate electrical measuring instruments are sometimes enclosed in heavy cast-iron boxes. To protect a delicate device the box is encircled with a soft iron screen and this tends to conduct the lines of force of the field around it, thus leaving the central cavity free (Fig. 15).

As we have seen, the magnetic lines of force extend in all directions from the poles of a magnet. They may be concentrated by attaching soft iron pole pieces to the poles of the magnet (Fig. 16). Between—but not touching—these pole pieces another magnetic body may be placed; this body is called the *armature*. When a coil of wire so placed is rotated, an electric current is produced in it as it cuts through the lines of force of the magnet. This is the principle of the dynamo of electrical current.

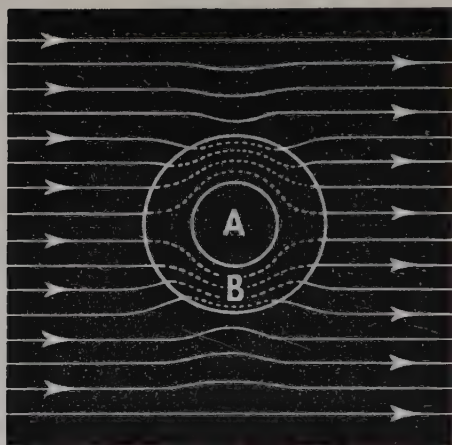


Fig. 15. Showing how an iron tube (B) acts as a magnetic screen, conducting the lines of force from a magnetic field away from the inner cavity (A), leaving it free from interference

There is a close connection between magnetism and electricity and many important applications in industry and science are entirely dependent on this fact.

A current of electricity flowing through a wire is surrounded by a magnetic field. If the current flows in a circular path around a loop of wire, the effect is that of a magnet with the line between its north and south poles at right angles to the plane of the loop.

One of the most important effects of an electric current is its magnetic effect, for it is by means of this that such appliances as the telegraph and the telephone are rendered possible. If a foot or two of insulated wire is wound about fifty times round a piece of iron rod—a poker or a large nail will serve the purpose—and the ends of the wire are connected to a battery or to a generator, the rod or nail will be magnetized as long as the current remains on (Fig. 17). The rod

will pick up tacks or pins, but immediately the current is disconnected these are no longer attracted and drop from the rod.

Even the strongest permanent magnet exerts only a small force compared with electromagnets. This is because the steel of a permanent magnet has a saturation point beyond which it cannot take up any further magnetism. On the other hand, an electric magnet can be composed of a large number of turns of wire around an iron bar or core. What happens is that the wire has circulating round it a magnetic field in a continuous series of lines, as though a magnet lay in the central axis of a tube. All the lines of force run in the same direction and their combined force even in one layer of wire is considerable. With additional layers wound closely together this force can be made very much greater, particularly when a heavy current is used—and currents of up to 5,000 or more



Fig. 16. A permanent magnet fitted with iron pole pieces, and armature in position

amperes are sometimes used, although only in the laboratory.

ELECTROMAGNETS IN INDUSTRY

Electromagnets have many applications in industry, particularly as solenoids for operating railway brakes, electric signals, and so on. Large electromagnets used for lifting metal are attached to a crane and lowered to the object to be picked up. The current is switched on, the magnet attracts the metal, is lifted and moved by the crane to the place required, when the current is switched off and the metal dropped into position. Voltmeters and ammeters use the same

magnets. We have seen, too, that the earth possesses a magnetic field, for a freely suspended magnet will set itself in a given direction. We should expect that a piece of iron would be magnetized if placed north and south in the earth's magnetic field, and in fact this can happen. A piece of soft iron will be magnetized fairly quickly—steel takes longer, though the process is assisted by hammering—the end of the bar facing north becoming the north magnetic pole of the magnet.

It is for this reason that iron pillars and railings become magnetized. When so magnetized, the iron and steel used in the construction of ships

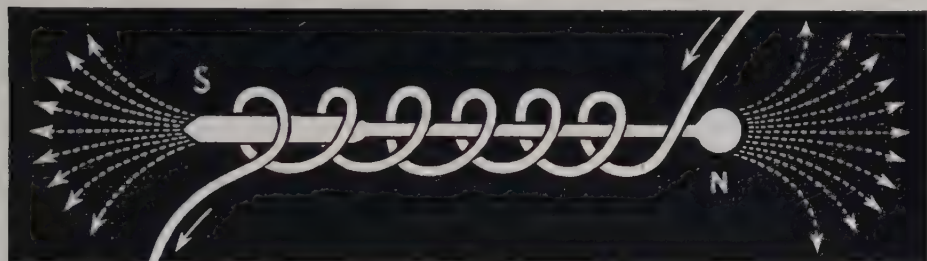


Fig. 17. If a number of turns of insulated wire are wound round an iron or steel bar such as a poker, and a strong current from a battery or generator is passed through the coil, the bar will become magnetized, showing north and south polarity like any other magnet

principle for measuring current—one very sensitive type of moving-coil galvanometer has a tiny mirror carried on a fine coil that hangs between the poles of a magnet. The mirror reflects a spot of light on to a revolving drum of sensitized paper or photographic film, and such a coil is so sensitive that it will detect a current of as low as one ten-thousand millionth part of an ampere—indeed a small amount of electricity!

We have seen that surrounding a magnet and surrounding an electric current there is a magnetic field in which pieces of iron or steel become

produce a disturbing effect on the ship's compass. In some cases it may affect the needle by as much as 20° . In the process required to overcome this difficulty, corrections, often of an extremely complicated nature, have to be applied. These generally take the form of sets of steel magnets placed at right angles to each other, their center being under the compass needle. These have the effect of setting up counterforces in soft iron spheres, placed one on each side of the compass, compensating for the magnetism ordinarily found in the ship's hull.

THE EARTH A HUGE MAGNET

Why does the earth behave as a magnet? It has been suggested that the earth's magnetism is due to the presence of magnetic matter within the earth, but this theory has not been accepted for it leaves much to be explained. We might suppose that the earth's interior consists largely of iron, for we know its density is high.



Fig. 18. A piece of iron placed near a bar magnet becomes temporarily magnetized

We have already seen that the rocks at the earth's surface are about two and one-half times as heavy as water, whereas the earth as a whole is over five times as heavy as a globe of water of the same size would be; iron has a density nearly eight times that of water. The objection to this suggestion is that the temperature of the earth's interior must be very high, for reasons we have already explained. Now iron loses its magnetism with heat, susceptibility vanishing abruptly when the temperature reaches 800°C . Evidently some important change in crystal structure takes place in the iron at this temperature, for its physical properties also undergo a marked change at or about 800°C . Thus, we can scarcely suppose that the huge mass of iron in the earth's interior can be in a magnetized state, despite the fact that one of the mysteries of science is how iron would behave under the enormous pressures to which it is subjected in the earth's interior. As we have seen, these may

amount to as much as 22,000 tons to the square inch.

A more probable explanation is that the earth is a huge electromagnet, the magnetizing currents being caused by streams of electrified particles that circulate in the higher atmosphere. According to this theory, daily variations would be caused by atmospheric oscillations of the same type as those that cause daily variations in atmospheric pressure and, therefore, in the weather.

Yet another theory is based on the fact that electrical charges are escaping from the earth into space. The source of these electrical charges has not hitherto been discovered and it has been suggested that the positive charges of electricity that form the nuclei of the atoms in the earth's interior are being converted into energy, and that the negative electrons are escaping and moving through the earth's crust, passing through the atmosphere into space. Thus, the earth may be continually disseminating electrical charges into space, and we know from simple laboratory experiments that a rotating electric charge causes a magnetic field.

This last theory is comprehensive, accounting satisfactorily for everything, including the source of the earth's internal heat. Theoretically the sun must also be a magnet—its material, we know, is similar to that of the earth; it, too, is hot; and it is rotating. The spectroscope shows that there is indeed an enormous magnetic field around the sun. At the sun's poles the magnetism is over 100 times its value on the earth, and in and around the sunspots, some 40 times, thus confirming the theory in regard to the earth.

When a soft iron bar is brought near to a magnet it acquires tempo-

rary magnetic properties—for example, it will attract iron filings (Fig. 18), and show polarity, or attraction and repulsion to the opposite or similar poles of another magnet.

The degree of magnetic power it acquires depends on the strength of the magnet and on its distance from the magnet, being greatest when in actual contact. In these circumstances the iron is said to be magnetized by induction. If steel is used instead of soft iron, the inductive effect only becomes manifest after the lapse of a certain time. On the other hand, when the magnet is removed, the steel bar does not immediately lose its induced magnetism, whereas the iron loses it immediately the magnet is withdrawn.

WHY STEEL RETAINS MAGNETISM

We may ask why this happens. The answer to the question is that every atom of a piece of iron is a separate magnet that is capable of turning on its axis. When a magnet is brought near an iron bar, all the atoms turn so that the north poles point in the same direction, and the iron bar itself possesses temporary magnetic powers. In the case of steel, however, there is this dif-

ference—that between the atoms of iron are atoms of carbon, and they tend to prevent the iron atoms from swinging with their poles in line. Continued application of a magnet to a steel bar overcomes this resistance, however, and the enemy becomes the friend, for the carbon atoms prevent the iron atoms from swinging back. Thus, the atoms re-



THE GIANT POWER OF MAGNETISM

Fig. 19. This man is being held up solely by the attraction exercised by the electromagnet for the nails in his boots. Notice the complete absence of supports

main permanently with their poles pointing in the same direction and the steel remains a permanent magnet.

Now let us see how each atom of iron can be a magnet. The answer is not far to seek. We know that an electric current is simply a stream of electrons flowing in a circuit from one terminal of a battery to the other and through the battery, so forming a continuous flow. We have seen, too, that atoms are believed to consist of electrons that are revolving in tiny orbits, so that in them we have the equivalent of an electric current and every atom should therefore be a magnet. Something must be wrong with this, however, for we know that not every atom is a magnet—we cannot magnetize brass or copper. Why? Because the non-magnetic substances are composed of atoms that have electrons

revolving in one direction which are equal in number to the electrons that revolve in the opposite direction—they pair off, as it were, with the result that their magnetic forces cancel each other out. The atoms of iron, on the other hand, have electrons that do not pair off, so that each atom resembles a minute electrical circuit capable of giving out a magnetic force. When magnetized, all these minute electrical circuits set themselves in the same direction—their forces are combined and manifest themselves as magnetism.

The question of how far different kinds of iron and steel become magnetized when placed in a given magnetic field is one of great practical importance. Most of the common metals are not attracted by magnets. Curious exceptions are certain alloys, which, although made of non-magnetic metals, themselves, may be magnetic. One such, for example, discovered by Hensler in 1903, is composed of 61 per cent copper, 24 per cent manganese, and 15 per cent aluminum—all practically non-magnetic separately, but strongly magnetic when properly combined as an alloy of these three component metals.



Courtesy of Igranic Co. Ltd.

A CRANE USING AN ELECTROMAGNET

Fig. 20. The electromagnet on this crane measures 43 inches in diameter. Such cranes are particularly useful for railway assembly work as they eliminate a great amount of handling of the loads

LINES OF FORCE AROUND A WIRE

Exactly as there are so-called lines of force around a magnet, so there are lines of force around a wire through

which an electric current is passing. These lines of force can be shown by passing a wire through a card so that it stands perpendicular to the card. If iron filings are now sprinkled on the card and the ends of the wire connected to a battery, the filings will arrange themselves in concentric circles with the wire as a center (Fig. 21). They do not begin at a north pole and pass to a south pole as in the case of a magnet, for there are no poles in a wire. Each line of force is a circle, having neither end or beginning.

There is, of course, a close connection between magnetism and electricity and the study of the one subject necessarily goes hand-in-hand with that of the other. In times to come, no doubt, the present will be known as the Electrical Age, for year by year



Fig. 21. Showing that magnetic lines of force exist around a wire through which an electric current is passing

electricity is playing an increasingly important part in our lives, increasing the amenities of modern civilization. So universally is electricity now used, and so familiar have the phenomena associated with its application become, that its existence is taken for granted in much the same way as is the air we breathe.

Let us see if we can now learn what electricity is and how it can be used.

First, we must realize that it is not possible to define electricity in the same manner as one would define the power exerted by the rapid burning of an inflammable mixture like gasoline, or by expanding steam. It may be said to exist as one of the many phenomena of nature that are only made manifest when following certain natural laws. These laws are manifest, irrespective of whether they are fulfilled or reproduced naturally, as in the case of lightning, or by mechanical or chemical means, as with the dynamo and battery. The form of energy we term electricity is present whenever matter exists.

In our consideration of the question "what is electricity?" it will be necessary for us to traverse again some of



Courtesy of Igranic Co. Ltd.

Fig. 22. A large solenoid for electrical control

the ground already covered in our section dealing with the constitution of matter. As we saw there, matter is defined as anything that occupies space, whether it is a solid, liquid, or even an invisible gaseous substance.



Fig. 23. Sealing wax or glass rubbed vigorously with silk attracts small pieces of paper

The electronic theory of matter, which was put forward at the beginning of the present century, gives us a basis for understanding the source of electrical energy. As we have already seen, it is believed that each atom is made up of a nucleus, consisting of a minute amount of positive electricity and a number of other particles that are attracted to this nucleus consisting of negative electricity. The negatively-charged particles, or electrons, are considered to be in a state of constant movement about the nucleus.

ATTRACTION BETWEEN CHARGES

This theory also accounts for the fact that particles containing different charges of electricity have a natural attraction for each other, and similarly charged particles have a natural repulsion. It is supposed that electrons are the constituents of all atoms

of matter and that they are identical, whatever the source from which they are obtained. Also, by various natural and artificial means, electrons can be made to move from one atom to another.

By so removing them a body will have a deficiency of electrons, or negative electricity, and an excess of positive electricity. Where electrons are transferred to a body, it will have an excess of negative electricity. In such cases the bodies are said to be negatively or positively charged with electricity.

STATIC ELECTRICITY

These conditions are readily shown by the familiar experiment of rubbing a glass rod with a piece of silk. This produces a static or stationary charge of electricity on the surface of the rod, enabling it to attract light articles, such as silk threads, small pieces of paper, and the like (Fig. 23). This power of attraction was known to the ancient Greeks and Romans, who demonstrated it by rubbing amber. The Greek word for amber was *elektron* and it is from this that we derive our word "electricity." Thales of Miletus, born about 640 B.C., was the first to study the subject, but after his time it seems to have been forgotten until Gilbert, Queen Elizabeth's physician, took it up about the end of the sixteenth century.

The process of rubbing a glass rod transfers electrons from the rod to the silk, and by their flow through one's hand and body to the earth, they leave the atoms in the surface of the rod with an excess of positive electricity. If the material with which the rod is rubbed is insulated from the earth to prevent the escape of the excess electrons, it will be found to have

an excess of negative electricity and is then said to be negatively charged. On the other hand, if a rod of amber, sealing wax, or vulcanite is treated in a similar manner, electrons are transferred from the silk to the rod, so that the rod becomes negatively charged and the silk positively charged.

This can also be demonstrated by a phenomenon that no doubt everyone has noticed when combing his hair. A light crackling is heard, due to the transference of electrons between the hair and the comb. It will even be found that if the comb is made of one of the popular plastic materials, it will attract very light articles. The light stroking of the hair of an animal such as a cat will produce the same effect, and in a darkened room there will be seen faint bluish sparks at the ends of the hairs as the hand passes over them, indicating the passage of the electrons.

All natural states are states of equilibrium. Therefore, if two negatively or two positively charged bodies are brought into contact, they tend to repel each other, for there is no tendency for the electrons to move from one body to another, since each has a similar excess or deficiency. If bodies having dissimilar charges are brought together, however, they attract each other. The electrons flow from the body with an excess, to the body that has a deficiency, until each has an equal amount and they are in equilibrium.

WHAT DISCHARGING MEANS

When electrons flow in this manner the electrified bodies discharge. When the flow ceases and the bodies are in equilibrium they are said to have been discharged.

The form of electricity we have so far considered is known as static electricity, or electricity at rest. Static electricity is of little interest except for experimental purposes, for it cannot be made to do useful work. As we have seen, it can be made to give a power of attraction to certain things, such as a pipe mouthpiece or a stick of sealing wax, so that it will attract small pieces of paper, tobacco ash, or pith, in a manner similar to that in which a magnet attracts tacks.

EARLY ELECTRICAL DISCOVERIES

After Gilbert published his *De Magnete* many experimenters investigated static electricity. They soon realized the necessity of finding some means of providing larger charges than could be obtained by rubbing glass rods with silk and they devised machines to carry out the rubbing processes on a larger scale. The first of these machines was constructed by Otto von Guericke (1602-86) of Magdeburg. It consisted of a globe of sulphur mounted on a rod and excited by the application of a cloth. Later, Sir Isaac Newton used a glass globe

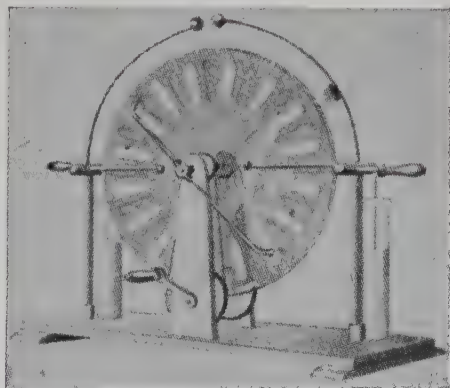
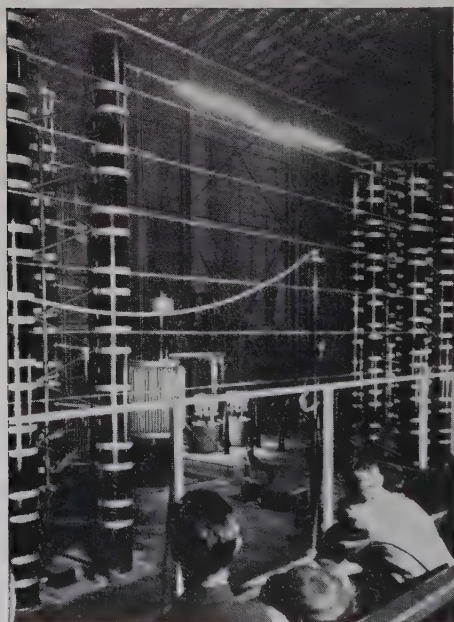


Fig. 24. A Wimshurst machine for producing charges of so-called static electricity

instead of sulphur, and leather pads as a source of friction. These early machines were followed by others in which the essential feature was some mechanical arrangement for rubbing glass cylinders against specially prepared cushions, and from this fact they became known as friction machines. Later these friction machines were superseded by "influence" machines, one of the best known of which was designed by James Wimshurst about 1878 (Fig. 24). In it glass or ebonite plates are caused to rotate rapidly, brass rods collecting the current through combs and becoming so highly charged that sparks pass between them if they are brought close together.



General Electric Co.

Fig. 25. Before the New York World's Fair closed in 1940, millions of visitors thrilled to man-made lightning, such as this 10,000,000-volt lightning stroke in Steinmetz Hall of the General Electric Building

WHAT IS LIGHTNING

There is a striking resemblance between these sparks and lightning, in fact, the sparks are merely miniature lightning flashes. The charges on the rods are prevented from passing by the intervening air gap, for air is a non-conductor of electricity. As the charges increase in strength they reach a degree at which the electricity is strong enough to overcome the resistance of the air, and a brilliant spark results, the molecules of air being rendered luminous. Benjamin Franklin was the first to show that lightning is simply a huge electric spark. In 1782, he flew his famous kite in Philadelphia and drew electric sparks from the kite string.

Lightning is simply a gigantic spark between the earth and a cloud, or between two clouds. It occurs when opposite charges of electricity become strong enough to overcome the resistance of the intervening air. Forked lightning is due to the discharge taking the path of least resistance through the air. Sheet or "summer" lightning is merely the reflection from the clouds of forked lightning at a distance. In this case the distance is so great that the thunder accompanying the discharge generally is not heard. A flash of lightning may be several miles in length, the largest on record being about ten miles.

Thunder is due to the expansion of the heated air along the track of the flash, followed by a sudden rush of air into the vacuum formed thereby.

Until now, then, we have been dealing only with static electricity which is of no practical use. The electricity we use in ordinary life is known as current electricity, which, as the name implies, is electricity in motion.



Fig. 26. This photograph of a 1,000,000 volt nine-foot three-phase spark shows clearly how the line of a spark moves about in the air, finding the path of least resistance

An electric current may be defined as a drift or flow of electrons from one atom to another, induced either by natural or artificial means.

When a current is made to flow through a wire this is actually the drift of the negative particles of electricity from atom to atom. Although

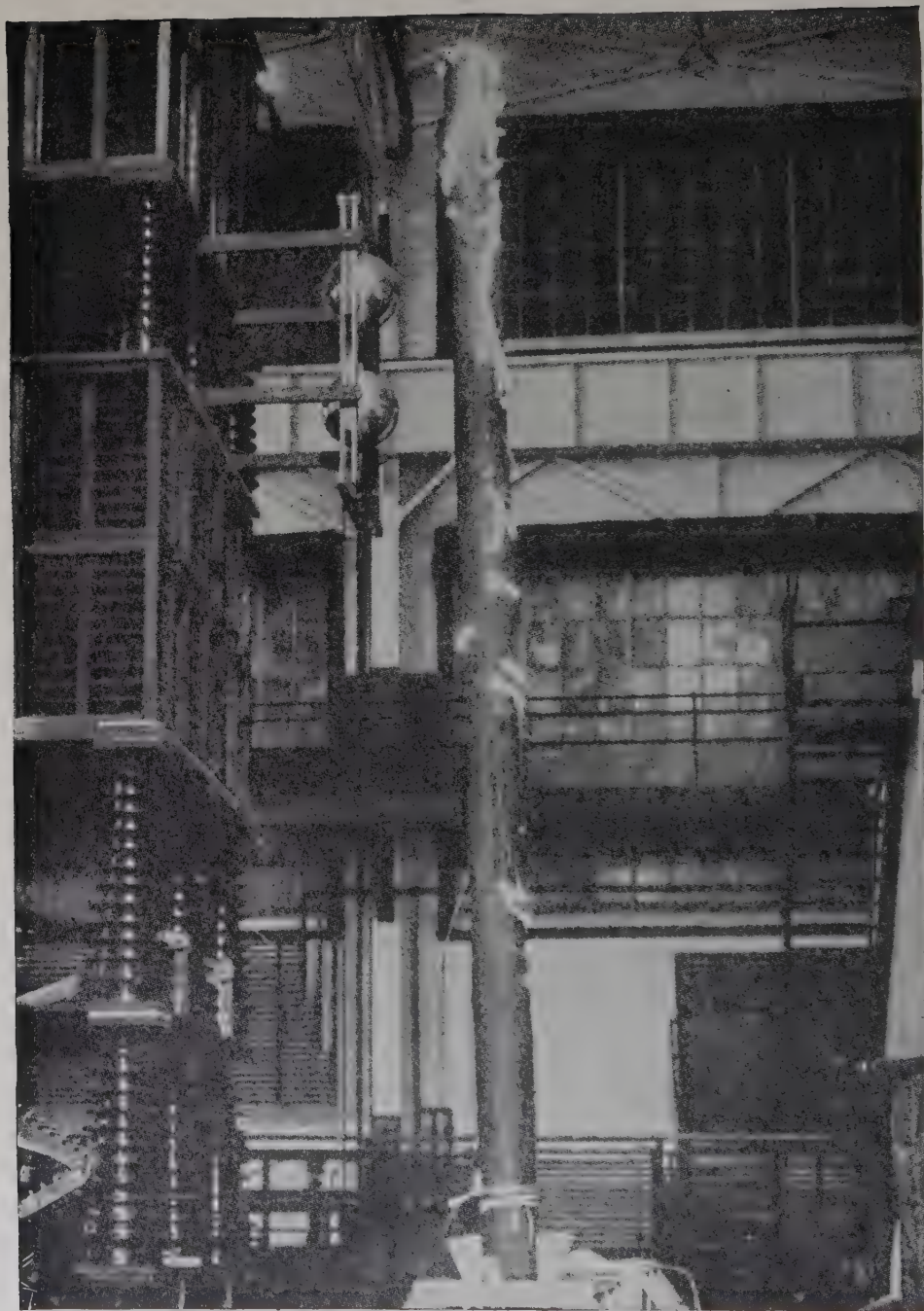


Fig. 27. What happens when lightning strikes a telegraph pole? This picture shows a 20 foot timber being split by an artificial spark of over 3,000,000 volts

we think of electricity as traveling so fast as to appear almost instantaneous, the rate of progress is actually very slow. The electrons drift or flow from atom to atom at a rate of possibly only a few yards per hour. However, as previously described, two electrons, or particles of negative electricity, being of like charge, repel each other, so that the electrons are displaced or repelled almost simultaneously in each atom throughout the whole length of the wire, giving an apparently instantaneous effect at a distance.

In 1796, Alessandro Volta, Professor of Physics at Padua, found that electricity could be produced by bringing two dissimilar metals into contact. He found that when copper and iron were placed in contact, one became positively charged and the other negatively charged. By alternatively placing a number of discs of these metals and insulating them from one another with pieces of flannel, he was able to obtain a continuous supply of electricity, which renewed itself as quickly as it was used. He found that the best results were obtained when the metals were placed in a vessel that contained dilute acid, and his arrangement is known as the voltaic cell. It consists of a glass jar containing dilute sulphuric acid, in which hangs a plate of zinc and a plate of copper. When the plates are connected by a wire, a current of electrons flows along the wire from the zinc (negative) to the copper (positive) plate. Within the cell a chemical change is taking place which liberates energy. Atoms of zinc each have two electrons in their outer shells. These atoms go into solution from the zinc plate as positive ions (see page 234) by each leaving its two valency electrons be-



Fig. 28. A Leclanché cell

hind. These are the electrons which are flowing out of the zinc plate through the wire to the copper plate. At the surface of the copper plate some change must take place which will use up the electrons as they flow into this plate through the wire. At this pole the hydrogen ions from the sulphuric acid (H_2SO_4) gain an electron apiece, and the resulting neutral atoms combine in pairs to form molecules of gaseous hydrogen. By this means, therefore, chemical energy is converted into electrical energy.

PRIMARY CELLS

The voltaic cell was found to be inefficient and it was subsequently superseded by improved cells. Of these, the best known is the Leclanché, consisting of a glass jar filled with a solution of sal ammoniac in which is placed a rod of zinc (Fig. 28). The chemical action that takes place when the current is flowing results in the wasting of zinc. Actually, when the cell is at rest, chemical

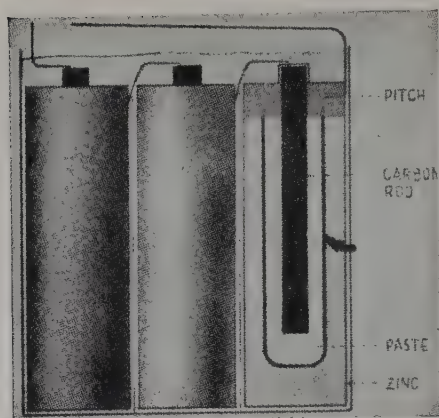


Fig. 29. Construction of a simple flash-light battery. One cell is shown in section

action continues to a certain extent owing to the impurities contained in commercial zinc, and the rod wastes away, but this can be obviated by coating—or amalgamating—the rod with mercury.

Also immersed in the solution is a porous pot containing a plate of carbon, around which is packed a mixture of crushed carbon and manganese dioxide. The carbon is the positive pole, the zinc rod the negative. Leclanché cells are used extensively where current is required occasionally and for short periods, as for such purposes as ringing house bells.

A modified form of the Leclanché cell is the so-called “dry battery.” Actually these batteries are not dry, for if they were there could be no flow of current. In a dry battery the zinc rod is replaced by the containing vessel, and the liquid by a moist paste that surrounds a carbon rod in the center of the cell (Fig. 29). The whole cell is sealed at the top and placed inside a closely fitting tube. Such dry batteries are in use for all manner of purposes from flash lamps to radio receivers, their great advantage being

the ease with which they can be carried about and placed in any position.

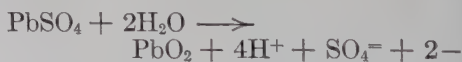
Voltaic cells, Leclanché cells, and other similar cells, as well as dry batteries, are known as primary cells. They produce electric current from chemical action, converting chemical energy into electrical energy.

STORAGE BATTERIES

Everyone is familiar with the convenient way in which the storage battery (Fig. 30) of a motor car stores electrical energy from the generator when the car is in motion and releases this energy when it is needed to start the motor or to operate the horn or lights. A completely uncharged cell in such a battery consists of two lead plates coated with lead sulphate (PbSO_4) immersed in dilute sulphuric acid. When the battery is being charged, the following change takes place at the pole connected to the negative lead from the generator:

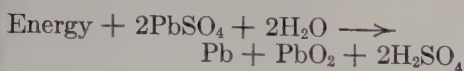


This chemical equation means that the lead sulphate of the plate takes up electrons which flow into the plate and is changed to metallic lead and sulphate ions which go into the solution. At the other pole from which electrons are flowing through the positive lead of the generator, this change occurs:



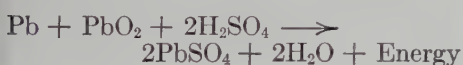
From this equation we see that the lead sulphate plate is converted into lead dioxide which process releases electrons which join the stream flowing out through the positive lead to the generator. If we add up both

equations, remembering that two hydrogen ions and a sulphate ion are equivalent to a molecule of sulphuric acid, we obtain for the complete reaction of charging:



This is a reaction which stores the electrical energy as potential—in this case chemical—energy in the molecules of the products. By examining this equation we are also able to explain why the specific gravity of the solution increases as the battery becomes more fully charged. It will be noticed that sulphuric acid is formed in the charging process and hence the specific gravity of the solution becomes greater.

When electrical energy is to be withdrawn from the battery, its poles are connected to the starting motor or to the headlight bulbs and the electrons flow in the opposite direction from that which they followed when the battery was being charged. The chemical change which now produces electrical energy is the exact reverse of the charging reaction:



ELECTRICITY AND MAGNETISM

Such cells and batteries are not capable of providing the electrical power necessary to do the world's work. For this power we rely on the dynamo or electrical generator.

In 1819, H. C. Oersted, Professor of Physics in the University of Copenhagen, discovered that iron filings will cling to a wire through which a current is flowing and that when the current is stopped they fall off. This discovery established the fact that

during the passage of electric current the wire becomes a magnet, and that it loses its magnetism when the current is switched off.

In 1831, Michael Faraday, interested in Oersted's discovery that magnetism could be produced by an electric current, became convinced that it should be possible to produce the reverse effect and make magnetism produce electricity. He found that if a magnet is moved towards or away from a coil of wire, or if the wire be moved to or from a magnet, an electric current is induced.

PRINCIPLES OF THE DYNAMO

Faraday's discovery established the relationship between the loadstone and current electricity, and showed the relationship between electricity, magnetism, and motion. It made clear, too, that electrified bodies in motion produce magnetic fields around themselves, and that a magnet in motion creates a current of electricity in con-

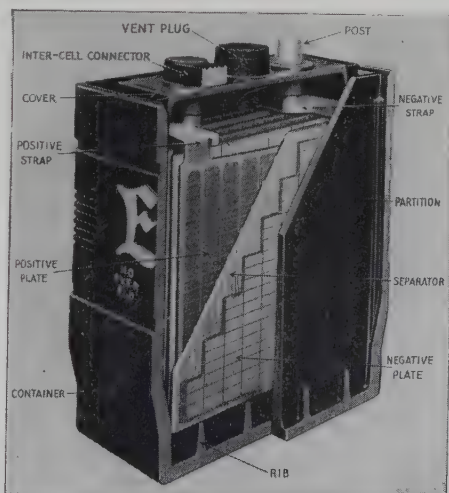


Fig. 30. Cross section of storage battery commercially used as source of electrical energy

ductors that are close to it. These discoveries are the basic principles of the dynamo, the most familiar electricity-producing machine. No matter whether this is a small machine for lighting a bicycle headlight, or a very large and powerful one for providing a town with light, heat, and power, the principles are the same.

As we have seen, magnetism may be considered as a force of attraction between opposite poles. Instead of being termed positive and negative, these points are called north and south poles respectively.

affected by either natural or artificial means. In the dynamo we have an example of the employment of both these means.

If a loop of a coil of wire is placed between the poles of a magnet and remains at rest, the flow of magnetism has no effect in causing a flow of electrons or electric current. On the other hand, if relative movement is made to occur between the wire and the lines of magnetic force, movement of the electrons takes place and an electric current is said to flow. A current caused in this manner is said to be induced, as there is no mechanical or electrical connection between the magnet and the wire.

NATURAL LAWS OF MAGNETISM

This movement has to be made in accordance with certain natural laws, however. First, to obtain the maximum effect, the lines of magnetic force must be moved across at right angles to their flow by the wire loop or conductor. Second,

as this angle of movement is altered, the current induced in the conductor decreases until if the conductor moves parallel with the lines of magnetic force, no current is induced in the electrical connection.

A further natural law controls the direction of the current flow, so that when the conductor is moved across the lines of magnetic force in one direction, the flow of current occurs in a certain direction in the conductor.

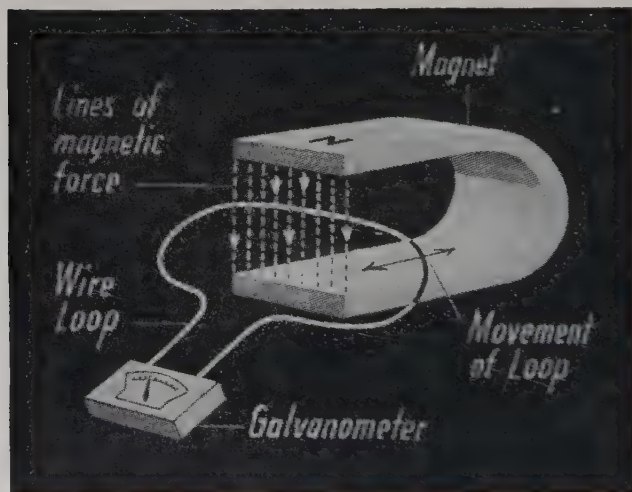


Fig. 31. Illustrating the principle of induced current

We have also explained that magnetism does not depend on a conductor such as a wire to permit it to act between poles, but is capable of existing in space. It cannot be insulated, or prevented from flowing, as can an electric current. For convenience, this flow, which is referred to as "lines of force," is considered to flow from a north pole to a south pole.

The movements of electrons that form an electric current may be

When the lines of force are moved across in the opposite direction, the flow of current is reversed. This can be shown by the extremely simple experiment of connecting the two ends of a wire loop to a sensitive current-measuring instrument, such as a galvanometer, and passing the loop in the manner described above between the two arms of a horseshoe-type permanent magnet (Fig. 31). When the loop is moved in one direction the galvanometer needle will be seen to swing in that direction, but when the movement of the loop is reversed the needle will swing in precisely the opposite direction that it previously occupied.

From this principle of operation it will be seen that means would have to be provided to enable the coil of wire repeatedly to cut across the magnetic

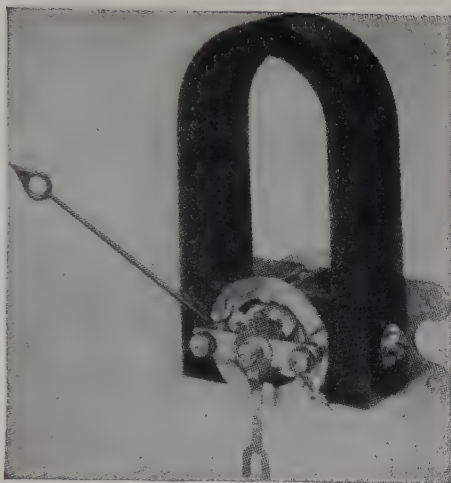


Fig. 32. A moving-coil ammeter. As in the voltmeter the coil swings between the poles of a horseshoe magnet

lines of force. As the simplest of all mechanical motions is that of rotation, it follows that the whole of the coil should be situated between the poles of the magnet. These should be rotated about an axis that will permit the loop of the coil to cut the lines of force at right angles to their flow. If the current is now picked up from the rotating coil, we have the dynamo in its simplest form. Illustration of this machine is seen in Fig. 33.

KINDS OF CURRENT

The terms "direct current" and "alternating current" are often heard as applied to dynamos. Fundamentally,

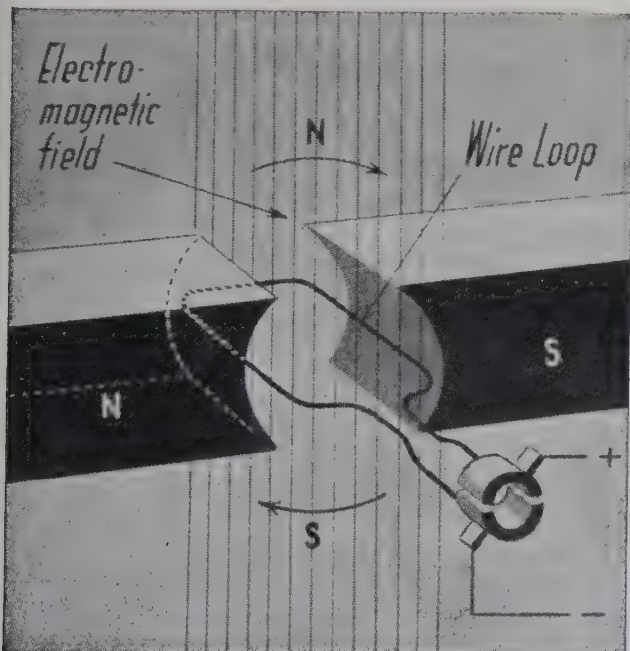


Fig. 33. Magnetic field through loop attracted by permanent field

all dynamos are of the alternating type and it is only by their mechanical construction that they are able to produce either current as required by the designer. Let us stop for a moment and consider why this strange condition should be so.

When the wire coil is rotated in the manner described above and is cutting across the lines of magnetic force at right angles to their flow, a current is generated in the wire loop. This current flows in a certain direction, according to the direction of rotation as shown in Fig. 34. If we consider the side of the wire loop adjacent to the north pole of the magnet, we see that by rotating the loop in a clockwise direction the flow of induced current, obeying the natural laws, also flows in a clockwise direction in the loop, as shown in the diagram. If the

two ends of the loop are connected to two metal collector rings, which rotate with the wire loop and permit sliding contacts to collect the current from them as it is induced, a voltmeter, or similar electrical recording instrument, connected to the contacts of the device will indicate the flow (Fig. 34).

In this case the induced current flows from ring A through the loop to ring B. If these rings are connected to an outside circuit, such as an electric light circuit, the current flow induced will also be in a similar clockwise direction.

If the wire loop is given half a revolution so that the other side is adjacent to the north pole of the magnet, although the current still travels clockwise round the whole loop, it is traveling towards the collector ring A

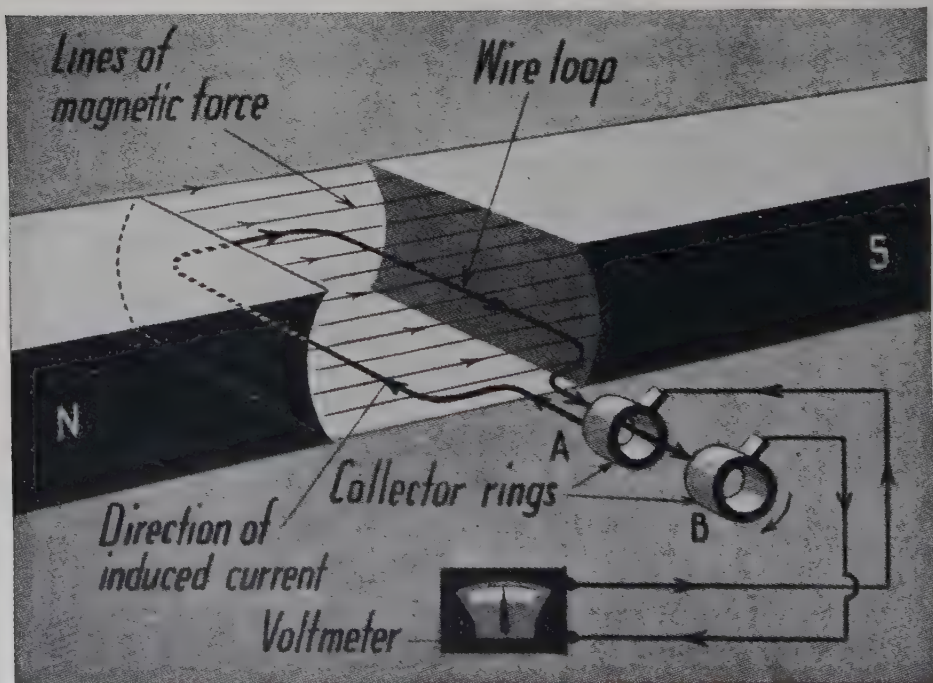


Fig. 34. Illustrating the principle of the induced alternating-current dynamo

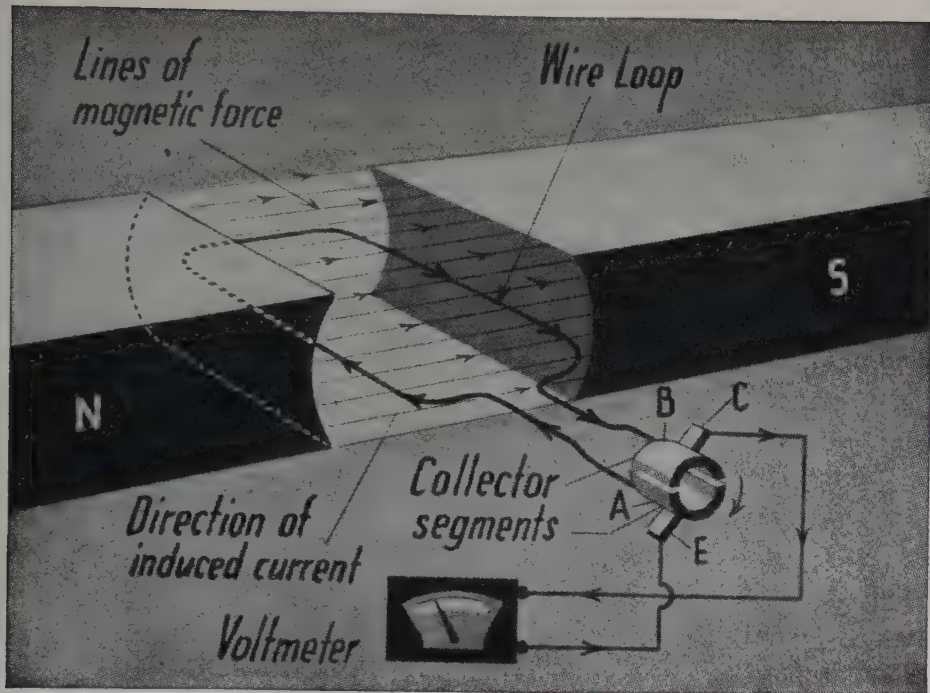


Fig. 35. How a dynamo produces direct, as opposed to alternating current (see Fig. 34)

from the ring *B*. As these rings are permanently connected to the outside circuit it will be seen that the current flows in this circuit first clockwise and then anti-clockwise. From this reason it is called alternating current—actually it is an alternate surging to and fro of the electrons in the wire.

DIRECT-CURRENT DYNAMOS

We have stated that basically all dynamos produce an alternating current. Let us see how a direct current can be obtained from a machine that normally would produce only alternating current.

In the direct-current dynamo no actual conversion of current is made, but by mechanical means the alternating current is so guided that the flow in the outside circuit is always

in one direction. Consider again the coil of wire rotating between the two poles of a magnet (Fig. 35). Instead of each end of the wire being attached to two collector rings, only one ring is used and this is split in halves, leaving a gap between the halves. Each end of the wire loop is connected to one of these collector segments. The two collectors (*C* and *E*), or “brushes,” as they are termed, are arranged to make contact one with each half ring when the wire loop is cutting the magnetic lines of force at right angles to their direction of flow.

If the wire loop is rotated as previously explained, the current is induced in the wire traveling in the direction from the half ring *A* Fig. 35 around the loop to the half ring *B*, and from the half ring *B* round the



Consolidated Edison Company

Fig. 36. A 160,000 kilowatt turbine generator, one of five of that capacity which supplies electric power to New York City

outside circuit in a clockwise direction back to the half ring A. When the wire loop is given half a revolution the current flows as previously from B to A. Owing to the rotation with the loop of the half rings, however, A is now in contact with brush C that previously was in contact with half ring B. As the current is now flowing from B to A, it is still passing out through brush C and returning out through brush E.

In obtaining this flow or surge of electrons, the wire cuts across the magnetic lines of force at right angles to their flow when the maximum current is induced. As the lines of force flow in practically straight lines from pole to pole of the magnet, and as the wire conductor travels in a circular path in this magnetic "field," it will

be seen that the lines are only cut at right angles when the conductor is at the center of either magnetic pole. On rotation in either direction, the angle at which the conductor cuts across the lines gradually decreases, until when the conductor is midway between the edges of the poles it is momentarily traveling parallel with the paths of the lines of force.

ALTERNATING CURRENT

This results in a gradually decreased induced current to the point where the conductor is traveling parallel with the magnetic field. No current is induced when further rotation gradually increases the angle at which the magnetic field is cut. There is a consequent increase in the induced current, until it again reaches

a maximum when the conductor is cutting the lines of force at right angles adjacent to the opposite pole, but the flow is now in the reverse direction.

If we were to draw a graph of the direction and intensity of the induced current we should get a curve as illustrated in Fig. 37, in which it will be seen that the current is in the form of a pulsation, first in one direction and then in the other. Now, in view of this we may ask how it is that we can get what is apparently a perfectly smooth flow of electricity.

If instead of one wire loop we form a number of wire loops all about the same axis of rotation, and if we connect the ends of each loop to just a segment of its appropriate collector ring, we can increase the number of pulsations per minute. Thus, if a graph is drawn of these pulsations it would take the form shown in Fig. 38, the number of pulsations being governed only by the number of coils. If these coils and segments are arranged to give a direct current, the graph would present the appearance shown in Fig. 39. This is due to the reverse, or negative, flow being transferred to the direction of original or positive flow, giving a continuous current.

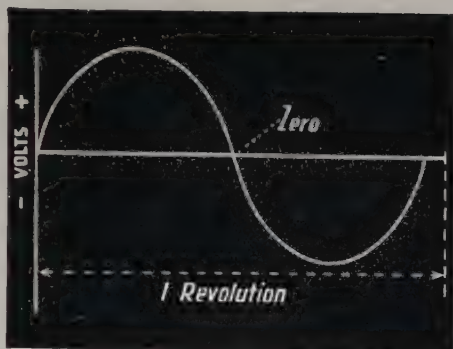


Fig. 37. Graph showing direction and intensity of an alternating current during one revolution

In actual practice the number of pulsations per revolution is often increased even further by arranging a number of magnetic poles around the wire coils. These are referred to collectively as the armature. In one revolution the wire loops cut through more than one magnetic field between north and south poles.

When alternating current is employed it is often referred to as being of a certain number of *cycles*. This indicates the number of times in a second that one of the magnetic fields is cut across at right angles by a wire loop. Clearly, it will depend not only on the number of loops in the armature and the number of magnet poles but also the number of revolutions per minute made by the armature.

From this we see that electric current from a dynamo is really made up of a number of rapid pulsations that may be 50 or 100, or more, per second, giving the effect of a steady flow.

On very small dynamos permanent magnets are used as being most convenient, but on larger types the magnets are of the electro type—that is to say, they are magnets artificially in-

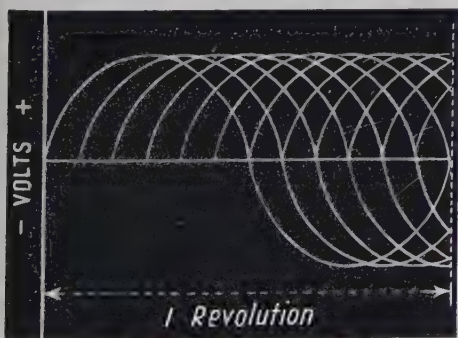


Fig. 38. A graph showing pulsations of a multicoin alternator



Fig. 39. A graph showing pulsations of a multicoil direct-current dynamo

duced by an electric current. An electromagnet is formed by an electric current being passed through coils of wire wound on a soft iron core. The strength of the magnetic field depends on the strength of the electric current passed through the windings, the magnet strength increasing with the current strength.

FIELD COILS

It would appear from this that it is necessary to have some extra means of providing current for passing through the magnet coils before an electric current can be produced by the dynamo. This is not necessary, however, for the following reasons.

First, each end of the magnet windings, or *field coils*, as they are termed, is connected to one of the brushes that pick up current from the armature. Thus, when the dynamo is gen-

erating current it is automatically supplying its own current for making the magnets. To use the usual term, it is said to be *exciting the field coils*.

When the dynamo is at rest, obviously no current is flowing through the magnet coils and therefore no electromagnetism is induced. Yet it is necessary for a magnetic field to be cut by the armature conductors before any electricity is generated. Although this seems an impossible combination without some external initial means of exciting the field coils, such means are fortunately not necessary. As we have seen in considering magnetism, the soft iron of which the magnet poles are made has the characteristic of retaining a very small

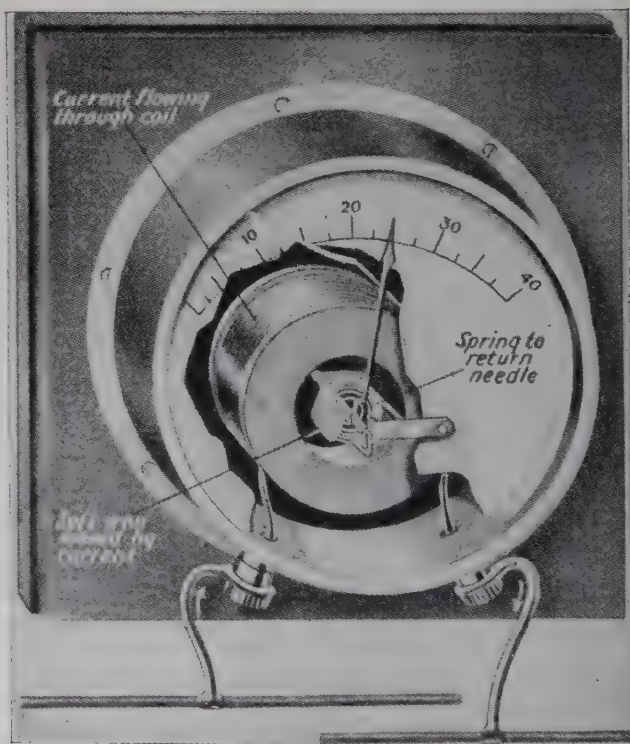


Fig. 40. A moving-iron voltmeter. The magnet is a coil of wire in the center of which is a soft iron armature

proportion of residual magnetism after the dynamo has stopped generating current.

When the dynamo is rotated, therefore, the armature first cuts through the very weak lines of magnetic force given off by the residual magnetism in the pole pieces, thus generating a very weak current in the armature windings. This weak current, passing through the magnet windings, increases the magnet strength. This, in turn, increases the current generated by the armature, the process continuing until the maximum current strength for which the dynamo was designed is reached.

Different windings are used for dynamos, and these are known as *series-wound*, *shunt-wound*, and *compound-wound* (Fig. 41).

The series-wound dynamo has the windings for the magnets so connected that the whole of the current generated in the armature passes through them before reaching the external circuit, as shown in the top illustration in Fig. 41. Where the windings form one continuous circuit, as in this case, the whole machine is said to be wound in series. As the load in the external circuit varies, so does the voltage, or pressure, of the dynamo current vary.

The shunt-wound dynamo, as the name implies, only passes a proportion of the armature current through the field-coils by means of a by-pass or shunt-circuit. Each end of this circuit is attached to one of the brushes through which the main current to the external circuit is passed, as shown in the middle illustration in Fig. 41. In this type of dynamo the current passed through the magnetic coils is directly proportional to the current generated by the armature. It

is practically independent of any load in the external circuit.

The compound-wound dynamo is a combination of both series- and shunt-winding as shown in the bottom illustration in Fig. 41. This type of dynamo is used when it is required to provide a constant pressure or voltage of electric current, irrespective of the load in the external circuit.

ELECTRIC MOTORS

As familiar as the electric dynamo is the electric motor that supplies

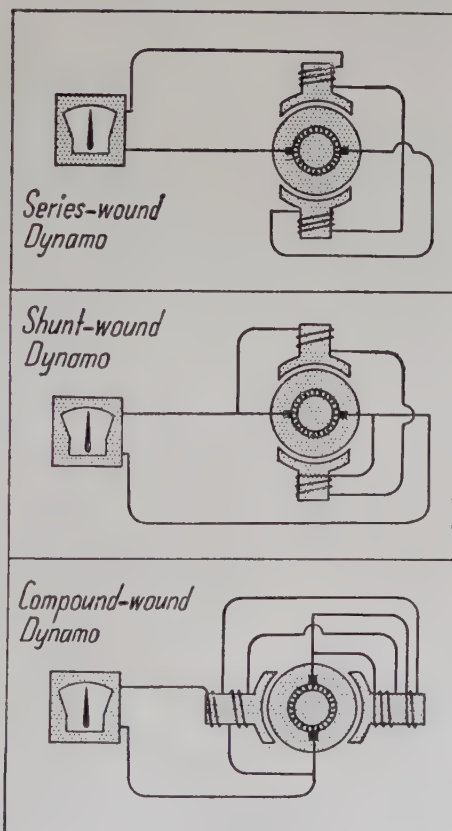


Fig. 41. Three types of generator in common use. The difference depends on the particular windings used in each case.

See text for explanation

most of our mechanical power requirements. In construction the electric motor is practically the same as the electric generator. It has the basic difference, however, that electric current from some external source is passed through the armature windings to produce rotation of the armature. It may seem strange that the same machine can give either electrical or mechanical power, but if we follow the natural laws governing magnetism and electricity we can realize why this is so.

We have seen that an electric current passed through a coil or wire wound on a soft iron core induces magnetism in that core. This characteristic is here made use of in a slightly different way. When a current is passed through a wire, a magnetic field is induced to circulate

around the wire in a direction depending on the direction of the flow of current. If, now, the wire with a current passing through it is placed between the poles of the magnet, it will be seen that on one side of the wire the magnetic field circulating round the wire is flowing with the field of the magnets and on the other side it is opposing the magnet field. At the top of the wire the magnet field is cut across in one direction by the wire magnetic field, and at the bottom of the wire it is cut across in the opposite direction.

These two magnetic fields tend to distort each other in a manner shown in Fig. 44. As the lines of force tend to flow in their normal path they can only do so if the wire moves in the direction of the weakest lines of force. This tendency for the lines of force to

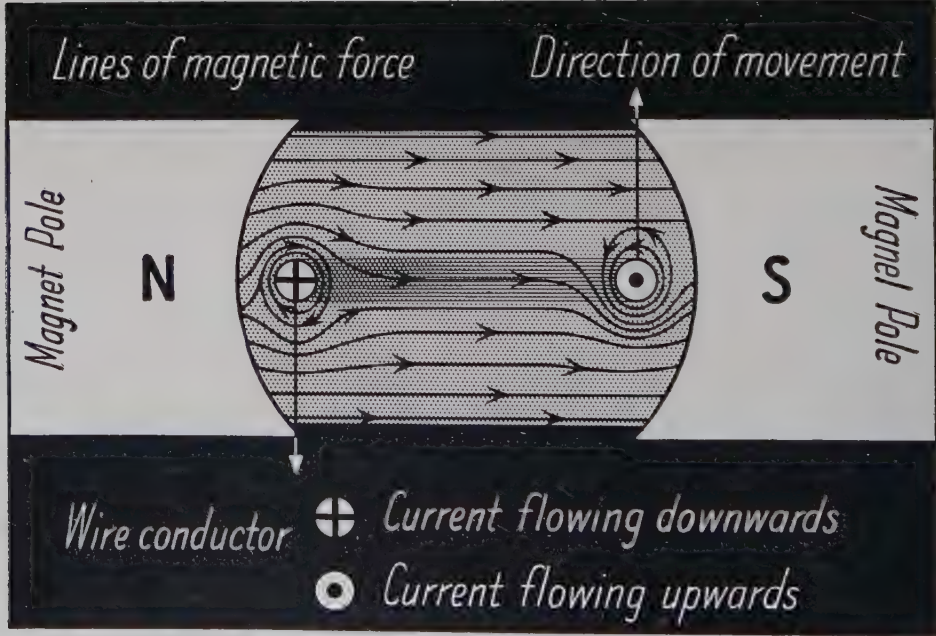


Fig. 42. Section of an armature showing clockwise and anti-clockwise flow of magnetic field

flow in a normal manner results in a force on that side of the wire where the flow of the magnet field is assisted by the magnetic flow round the wire.

If now the wire is formed into a loop, the same conditions exist, but the force is exerted on both sides of the loop in the same direction of rotation. This is illustrated in Fig. 42, which shows a section taken across the field magnets and the armature coil through which a current is passed.

If the current through this coil is considered to be passing downwards through the left-hand section, represented by a cross, the flow of the magnetic field at this point would be clockwise. As the current passes round the coil and travels upwards, represented by the



Fig. 43. A moving-coil ammeter. The coil is centered between the poles of a horseshoe magnet. See Fig. 40 for comparison

solid section, the flow is anti-clockwise. It will be seen, therefore, that the magnetic-field distortion is above the wire where the current is passing upwards, so that both sides of the wire loop are being forced in an anti-clockwise direction.

The maximum turning effort on the armature wire occurs when the wire is traveling at right angles to the lines of force. When the wire is at a point between the two poles no turning effort is exerted. In addition to this, as previously shown, magnetism is induced inside a coil of wire when a current is passed through. Irrespective of whether the wire is wound on a metal core, or whether a plain loop is formed, this magnetic field exists and has a north and south pole.

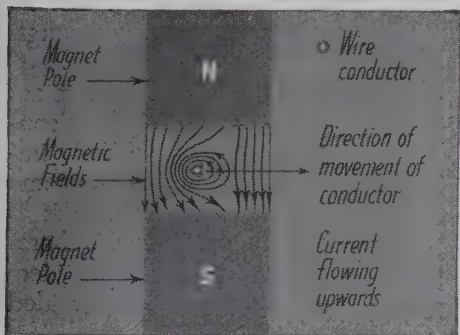


Fig. 44. How the magnetic fields in generators tend to distort each other. This figure is explained on this and the following page

MULTICOIL ARMATURES

When the wire loop of the armature is cutting the magnetic lines of force in the maximum turning effort position, a north and south pole is generated at points midway between the magnet poles, as shown in Fig. 45. As it is a natural law for poles of a similar kind to repel each other and for poles of opposite type to attract each other, a further turning effort is applied to the armature, and this gradually diminishes as the opposite poles come into line.

It is obvious from this that a single coil armature would not rotate, but would only turn until it reached the neutral position. If we add a second coil to the armature at right angles to the first, however, and connect the ends to segments of the collector ring in the same manner as a dynamo, the brushes through which the current from the external source is passed can be arranged in such a position that

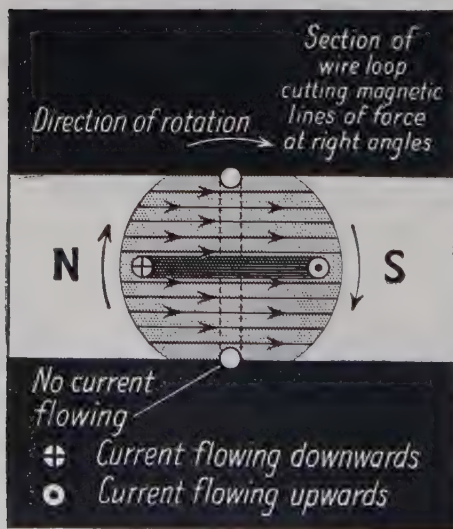


Fig. 45. Position of maximum turning force exerted on armature

when the first coil has reached the neutral position the segments attached to the ends of this coil have passed from beneath the brushes that now come into contact with the second coil through which the current is passed. This causes this coil to react in the manner already described, so continuing the cycle of operations.

In practice, a number of wire loops form an armature as in the case of a dynamo, so that the power impulses are so frequent as to give a practically smooth and continuous turning effort.

RISK FROM "LIVE" RAILS

It is often asked why birds can stand without injury on highly-charged electric wires, such as overhead streetcar wires or overhead power cables, whereas when a dog or a human being comes into contact with the "live" rail on electric railways death generally results. This may seem extraordinary until it is remembered that for an electric current to flow, a complete path must be provided through some conducting substance or material. Normally this path is provided through the mechanism of the streetcar or train to the metal rails on which the vehicle runs. In the case of power cables it is through the apparatus connected to them.

When a body comes into contact with a power cable and is not in contact with anything else, the body immediately becomes charged the same as the cable. As it is termed, it is raised to a high potential and is therefore in an unbalanced condition electrically. As long as no path is provided to change this unbalanced condition, no flow can take place and no effects are felt by the body. If a path is provided by the fact that the body at the same time touches another conductor

—which may be another wire or some conducting material connected to the ground or even the ground itself—the path is completed and the current flows, with disastrous effects to the intervening body.

Should a dog jump on to the live rail on a railway, the action disconnects his body from the ground, and this prevents the current in the live rail from flowing. He could walk on the live rail providing he breaks contact with the rail before touching the ground. If he tried to step on to the rail or to step off, however, the path would be completed and he would be killed.

EARTH'S NEGATIVE CHARGE

As we have mentioned, the earth is thought to carry a negative charge of electricity, due to electrons continually being shot off from the sun at terrific speeds. Thus by raising the potential of any conductor—that is giving a positive charge—connection with the earth will permit an electrical balance to be obtained and the current will flow. This is illustrated by our radio sets, for the aerial picks up a positive charge and this, after passing through the set, is directed to the earth by way of the earth terminal.

Another example is the effect of lightning, which often discharges to the earth, owing to the charge in the thunder cloud being at a different potential from that of the earth. Any electric current always chooses the path of least resistance, and should this path be by way of property, damage is caused; or if by way of persons, loss of life. For this reason lightning conductors of metal having good conductivity are used on high objects, so that the high potential of the thunder

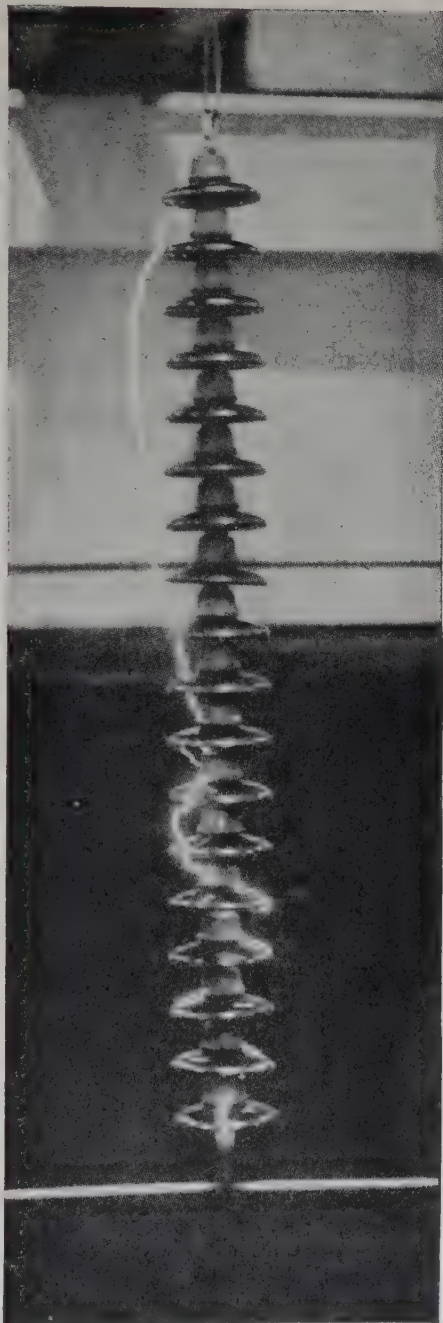


Fig. 46. Flaws in this insulator are being shown up by a flash of over a million volts

cloud can flow to the earth without damage.

We have spoken of the property possessed by various materials as being either conducting or insulating. By this we mean that a material either will readily permit the passage of an electric current, or it will offer such a great resistance to passage that no current flows. On the other hand, it has been seen that the electrons that form an electric current—under certain conditions—are a part of all matter. In view of this we may wonder why some materials will permit a current to flow more readily than others. Particularly in the case when there is what is called an insulator “break-down,” whereby it is made manifest that even those materials possessing the property of insulation can sometimes allow the flow of current.

No material is a perfect insulator, and providing that a sufficiently powerful electrical pressure can be applied, all materials will permit the passage of a certain amount of electricity.

It has been shown that all matter is composed of an assemblage of positively-charged nuclei, about which revolve electrons that are negatively charged. In any one material the number of electrons about each nucleus will vary, and it will be appreciated that owing to the infinitesimal distance between each nucleus the path or orbit of each electron system will overlap. Under these conditions a number of “free” electrons, which have less attraction to the nucleus than others, come into the field of attraction of an adjacent nucleus to which they are transferred by its attraction. This state continues throughout the whole body, so that there is a constant movement of electrons from

one nucleus to another. This preserves an electrical or potential balance, although the direction of movement is not constant and varies with each moving electron. According to the nature of the material, this transference of electrons takes place with greater or lesser ease. Fundamentally, it is this degree of ease that determines whether the material is a conductor or an insulator.

MOTION OF FREE ELECTRONS

It has been seen that two charges of different characteristics—that is, positive and negative—tend to attract each other. Therefore, if a positively charged object is applied to the material there will be a tendency to attract the negatively charged electrons. An electrical circuit is completed through a material when the positive and the negative leads from a current source are connected one to each end of the material. This tends to attract those electrons that are said to be “free” and are in a constantly moving state of transference. Thus, instead of their direction apparently being indiscriminate, they are attracted in one direction only—that is towards the positive side of the external current-producing apparatus being used.

We now see that a condition previously described is obtained, a condition of a controlled directional flow of electrons. As previously stated, these form an electric current and the magnitude of the flow is determined by the degree of conductivity of the material. If a considerable flow is obtained, the material is said to be a good conductor. On the other hand, if the flow is very small or apparently nil, the material is said to be a bad conductor, or an insulator.

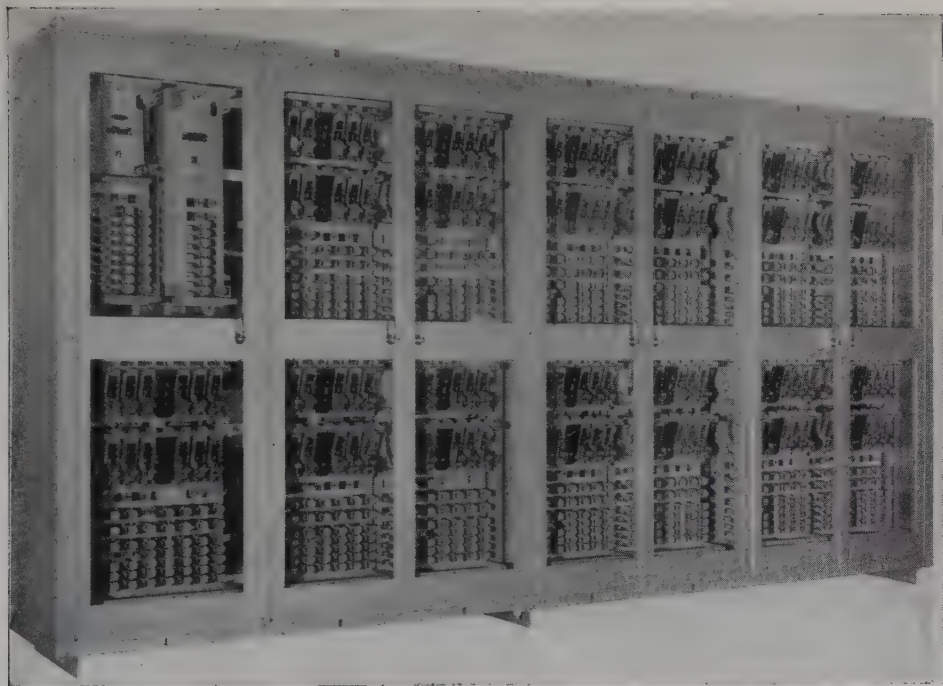


Fig. 47. The marvel of electricity is put to many uses. This electric totalisator is the pari-mutual machine which instantly registers your bet at the race track. The box contains 13 horse adding machines and the grand-total adding machine. Similar groups are used for the place and show pools

ELECTRICITY HARNESSSED

It is one thing to discover the cause of natural phenomena in the laboratory but it is another to apply this knowledge in controlling natural forces so that they may be turned to practical assistance in everyday life. All forces of nature are tremendous in their magnitude and if uncontrolled—or worse still, if allowed to escape from the control man endeavors to impose on them—they can cause enormous damage. This is especially true of electricity. The natural electricity that is visually manifest in the lightning flash is a potential source of great danger. To counteract this danger, it becomes necessary to employ

some means, if not of actual control, at least of guiding this force so that no harm results from its discharge. The lightning conductor does this by providing an easy path to the earth, but where no such easy path is provided anything in the path of this electrical discharge is destroyed. Everyone knows of the danger of being “struck by lightning,” where buildings, trees, animals, and human lives are lost through being in the uncontrolled path of this natural force.

No less dangerous is the electricity produced by man. Here the major problem is not the actual production, but the means of controlling the force so that it can be used for practical purposes. The mere production of

electricity is comparatively easy and not costly, and far greater expense is incurred in apparatus for its control and distribution.

Nature always provides some means of preserving a balance of forces. With electricity it may be said that such balance, or protection, is afforded by the various materials that have a natural property of resisting or preventing the passage of the current. These materials play a large part in assisting man to construct apparatus to enable him to control the force he generates.

CONDUCTORS AND INSULATORS

In the most common form of electric lighting, use is made of the property of resistance in a material. This form is the incandescent lamp, which in its earlier days contained what is known as a carbon filament. It was made from a paste of cotton wool dissolved in zinc chloride. The paste was forced through small holes into alcohol, so causing the paste "wires" to harden to allow them to be bent to the shapes required. These shapes were then packed round with carbon powder and heated to about 550°C ., and so were converted to the carbon filament ready for use which was sold commercially.

Such a filament offers a resistance to the passage of an electric current, and in overcoming such resistance the current is made to give a portion of its energy as heat. If the current is small, the amount of heat is so small that it is lost in conduction and radiation. On the other hand, if the current is large, an increasing amount of heat is given off and it will eventually be sufficient to cause the filament to become red, or even white hot, thereby giving the required light.

Exactly the same process occurs in modern lamps. Instead of a carbon filament they have one of metal—usually of tungsten wire—and in addition the air removed from the bulb is replaced by an inert gas. The purpose of removing the air is to prevent oxidation of the filament when heated, so causing early failure of the lamps. If the bulb is simply evacuated, tungsten atoms evaporate too rapidly from the filament and deposit on the glass. Thus the filament grows thinner and weaker and the glass is blackened. Filling the bulb with an inert gas, such as argon, reduces materially the evaporation of the metal and increases the efficiency and the life of the lamp.

Current in towns is conveniently distributed from powerful generators through switchboards and resistances direct to the lighting points. Where no such facilities exist, other methods have to be used to harness electricity in such a manner that its energy is available when required, irrespective of a continually working power station. In these cases the dynamo generating the current is driven by oil or gas engines, but instead of delivering the current direct to the lighting points, the dynamo supplies it to a battery of large accumulators. The lighting supply is drawn direct from the accumulators so that current is available even when the dynamo is not in operation. The dynamo set requires to be run only for comparatively short periods at a time to charge the accumulators sufficiently to replace the current used when it is idle. Apparatus of this type is often used in country houses and is also installed in many large city buildings as a precaution or reserve against a breakdown in the mains supply.

THE WORLD'S BRIGHTEST LIGHT

Another form of lighting is the carbon arc lamp. Here use is made of the fact that an intense spark occurs when an electric circuit is broken, due to the current endeavoring to continue to flow. A spark thus formed reaches very high temperatures and at its hottest point may be from $3,500^{\circ}$ to $4,000^{\circ}$ C., giving the intense glow of light that is characteristic of the arc lamp.

The two electrodes between which this spark is formed must obviously be of some material that will not melt under this extremely high temperature.

For this purpose carbon rods are used. The positive electrode is usually larger than the negative electrode as it is subjected to a greater degree of heat. Although carbon will not melt under the conditions, some burning takes place and a crater is formed on the positive electrode (Fig. 48). Here is generated the greatest heat, giving the major source of the light.

Arc lighting is extremely valuable where a point of light is required, such as in large movie projectors and searchlights. With the aid of mirror reflectors, an intense narrow beam can be obtained, such as would not be possible with a light given by a filament covering a comparatively larger area than the other.

POWER TRANSMISSION

Another familiar means of harnessing electricity is where it is required for power transmission. The modern method is commonly known as the

"grid" system, the poles of which are now a familiar feature carrying the cables overhead across the country. Here, use has been made of certain natural laws in order to overcome one of the greatest obstacles to the transmission of current over long distances.

We have seen that all materials, even the best of conductors, offer some resistance to the flow of a current. Therefore, a certain percentage of current is always expended in overcoming such resistances, before the remainder is available to perform work by means of various electrical devices.

It will be realized that when the distance over which the current is to be transmitted is very great, an enormous quantity of current would be required if users at the farthest end of the line were to obtain enough for their needs. To carry this would necessitate such extremely large and heavy conductors as to make such schemes entirely impracticable.

Now the electrical energy transported by a wire depends on two factors—the current (measured in amperes) and the electrical potential, or pressure (measured in volts). The same amount of energy may be transmitted at high voltage but low amperage, as at low voltage and high amperage. In the former case the loss due to heat is reduced, and the transmission more efficient. However, the voltage must be decreased by transformers before it is safe for household use.

When a coil of wire is placed close to, but not touching, another coil of wire, and the ends of the first coil are connected to a battery, it will be



Fig. 48. Showing the crater that is formed on a positive carbon electrode

found that on closing the circuit there will be a sudden surge of current in the second coil. If now the switch in the circuit of the first coil is thrown open so as to break the circuit, a surge of current will again occur in the isolated second coil. If a sensitive current-recording meter is connected to the ends of the second coil it will indicate that the direction of the current is the reverse of the current surge when the switch in the first coil circuit was closed. This phenomenon is termed induction, the current running in the second coil being known as an induced current.

TRANSFORMERS AND A.C.

It is not necessary to make and break the circuit in the first coil, however, to induce a current in the second coil. The same effect is produced if the primary current is reversed in its direction of flow, a current being induced in the secondary coil each time a reversal is made.

By varying the ratio of the number of turns of wire and the thickness of wire in each coil, it is possible to obtain from the secondary coil a current of different voltage from that supplied to the primary coil. If the primary coil consists of a large number of turns of fine wire, and the secondary coil of a comparatively small number of turns of a thicker wire, the induced current in the secondary coil will be of lower voltage than that supplied to the primary coil, and vice versa. In practice the coils are usually wound on a soft iron core to increase the magnetic field that is the cause of the induced current.

The transformer thus provides the means of overcoming a major difficulty in the transmission of electrical power. A small current is first gener-

ated at extremely high pressure, or voltage—possibly as high as 60,000 volts. Due to this high pressure, only relatively small conductors are necessary to carry small currents over long distances. This high-tension current is then led to a substation in the district it is intended to serve, and here it is fed into huge transformers. They convert it into a low-voltage current in sufficient quantity to serve a predetermined area, over which it can be carried by suitable conductors.

HEATING BY ELECTRICITY

Harnessed for further uses, electricity gives us heat in degrees of sufficiently wide range to serve both domestic and industrial purposes. Everyone is familiar with the electric "fire," or radiator, in which the characteristics of the energy of electricity in overcoming a resistance to its flow are caused to manifest themselves as heat.

The passage of a current of electrons through a conductor results in many collisions between electrons and the molecules of the conductor. The latter vibrate with increasing kinetic energy and the temperature rises. Should the body through which the current flows be small in proportion to the amount of current, and should the material be one having the characteristic of high resistance, the accelerated movement of the particles will be sufficiently great to cause the body to glow and radiate an appreciable amount of heat. Through this medium, the electric stove serves its purpose, the glowing elements being high-resistance wires to permit a heat glow. Radiation is assisted by reflectors of metal, or of some form of fire clay that projects the heat rays into the room.

The welding of metals is another use to which electricity is harnessed. Here, the heat of the arc between two electrodes is used to effect the necessary fusion. In this case, one electrode is formed by the metal that is to be welded and the other by a quantity of the same metal as that to be welded. This latter electrode, which is the one handled by the operator, is made in the form of thin rods of various thicknesses. This enables a light current and therefore a small arc to be used for fine work or for welding sheet metal where too intense an arc might cause burning of the job. Thicker rods are used where heavy jobs are undertaken, or where the mass of metal conducts heat away from the affected part very rapidly while the work is in process.

FLUX IN WELDING

As with all forms of soldering, brazing, or welding, some form of flux must be used to float to the surface the slag and impurities due to the oxidizing effect of the arc. For working convenience, this flux, in the form of a compound, is formed as a coating on the outside of the welding rod. Thus, as the rod fuses, a predetermined quantity of flux is also supplied directly to the weld. In operation, the welder holds the rod electrode in a special pair of tongs and strikes an arc at the spot to be welded. The intense heat of this arc immediately melts the end of the rod electrode and also a portion of the metal to be welded, so that complete fusion and mixing of the two metals is af-



Electro Metallurgical Co.

Fig. 49. The Shotweld process, a rapid method of welding stainless steel, is used in fabricating a stainless steel airplane stabilizer

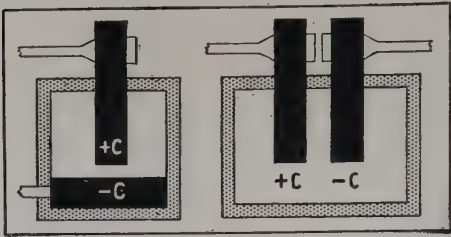


Fig. 50. Alternative arrangements of carbons as used in an electric furnace

fectured and the weld actually becomes a homogeneous part of the material on which the work was done.

Under test it has been found that a good weld actually is stronger than the original metal. Weld fractures are seldom experienced.

Welding is not the limit to which the heat of an electric arc can be used, however, for on a larger scale it is used as a furnace in which steel can be made. The electric furnace is extremely useful for producing steels of very high quality. An important factor is the intense heat which enables such impurities as sulphur and phosphorous to be almost eliminated.

Exactly the same methods are used in the electric furnace as in welding—that is, the charge fed into the furnace forms one electrode, a heavy adjustable carbon rod forming the other (Fig. 51). According to the size of the furnace, one or more carbon electrodes are used (Fig. 50), each being adjustable by external gearing to give the correct height in relation to the charge. Current from electric generators is supplied to the charge. It passes through this to the carbon electrodes and through them out of the furnace back to the generators to complete the circuit.

In the electric furnace use is made of the characteristic of the resistance of the charge, by first lowering the carbon electrodes until they are in contact with it. The current is then switched on and the resistance of the charge causes it to heat up to a point at which it is partially melted. Then the carbon electrodes are raised and carefully adjusted until an arc is formed between them and the surface of the charge. The heat formed by

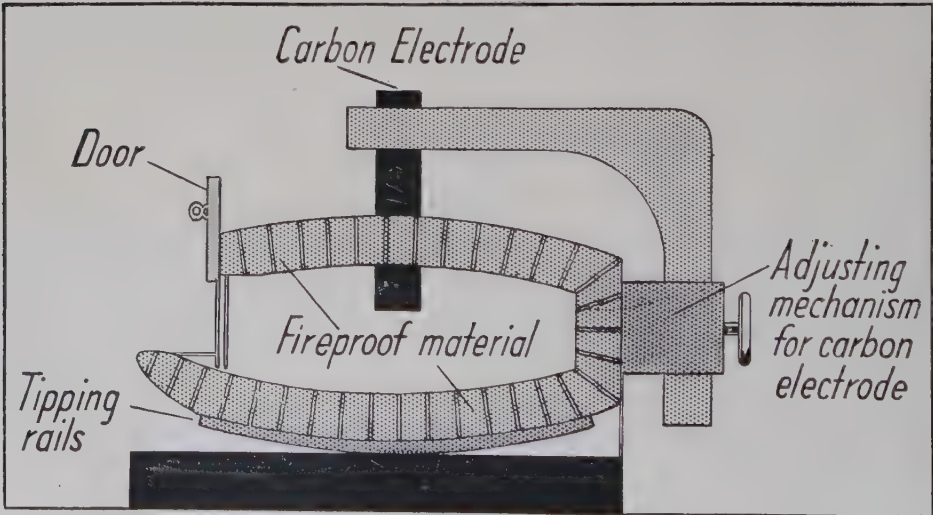


Fig. 51. Showing how electricity can heat a furnace by the arc method

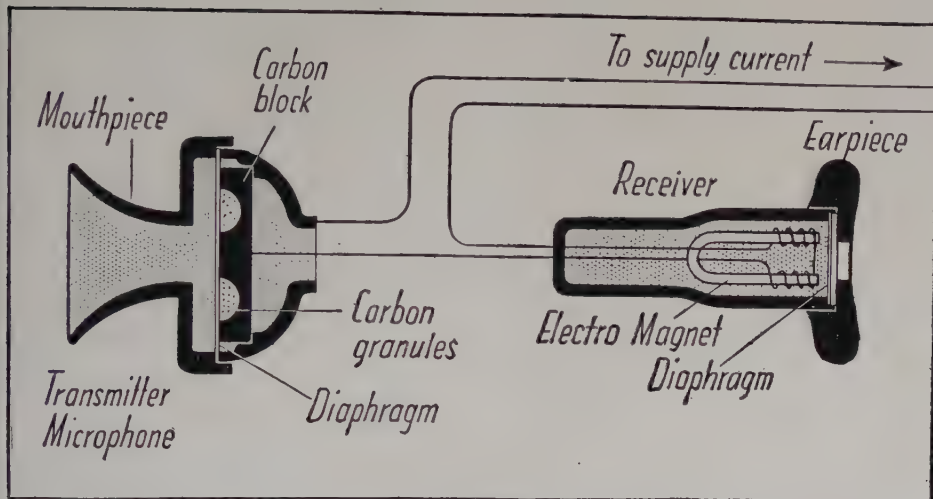


Fig. 52. Sound waves striking the diaphragm of the microphone alternately compress and release the carbon granules. Their resistance to the current flowing in the circuit is thus altered and these fluctuations in current produce variations in the pull of the magnet in the receiver. Its diaphragm is in turn caused to vibrate and so produce sound waves

such an arc is sufficient to make the charge fluid enough for working. It allows of the addition of other materials necessary for steel manufacture, and the formation of a fluid slag, the impurities of which are drawn off.

HOW THE MICROPHONE WORKS

The foregoing examples show the harnessing of electricity in comparatively large quantities, but this does not mean that only such large quantities can be harnessed to perform useful work. Even small quantities of electricity are harnessed to serve some useful purpose by the ingenuity of engineers in inventing and constructing suitable apparatus.

We take as an example of this, the transmitting microphone of the telephone and its receiver (Fig. 52). In the former, use is made of the characteristic of a carbon contact being of high resistance but extremely sensitive to mechanical disturbance. This

component has as its basic features a metal diaphragm and a carbon contact block, between which is a quantity of carbon granules to increase the points of contact between the block and diaphragm. Only a small current is now necessary for the microphone to operate in the following manner.

When a sound is made into the mouthpiece of the microphone transmitter, the sound waves so formed strike on the face of the diaphragm, and this vibrates in sympathy with them. This movement, which is imperceptible, is transmitted to the carbon granules and block. Owing to this vibrating disturbance, these alter the resistance to the passage of the current in the circuit through their points of contact. This therefore, alters in proportion to the amount of current flowing in the circuit. It only remains to record these fluctuations in current strength in a suitable manner to reproduce the sound.

For this purpose the effects of an electromagnet are used. The receiver is somewhat similar to the transmitter, but the soft iron diaphragm is placed very close to the two poles of a permanent magnet on which are wound a great number of turns of very fine wire. When the instrument is not being used, the lines of magnetic force flow from the north pole of the permanent magnet, through the soft iron diaphragm—although this is not touching the poles—and back to the south pole of the magnet. Thus,

a constant pull, or attraction, of predetermined strength, is maintained throughout in the diaphragm.

FROM SOUND BACK TO SOUND

As the ends of the magnet coils are connected in circuit with the transmitter, it will be seen that any variation in the current strength produced at the transmitter will be effected throughout the circuit and the magnet coils in the same proportion. Such variation of current in the magnet coils increases or decreases the



American Telephone and Telegraph Co.

Fig. 53. The wonder of electricity makes it possible for telephone calls to be put through to Bermuda, South America, Europe, Asia, Africa, and ships at sea

strength of the permanent magnet, as well as its attraction of the diaphragm, which under this varying attraction vibrates in exactly the same way as the transmitting diaphragm. Such vibration in the receiving diaphragm is immediately imparted to the air, in which waves are set up forming the sound it is intended to receive. This is merely the basic principle of one piece of modern apparatus for harnessing small quantities of electricity. Many refinements and additions are

made to enable greater convenience and use to be obtained.

The effects of harnessed electricity are seen on every hand. Our transport in the form of electric streetcars and trains, our elevators and cranes, conveyors and escalators, are driven by electric motors. Innumerable domestic appliances, and surgical and medical apparatus, result from the continual effort of man to harness to his needs one of nature's greatest and most potent forces.

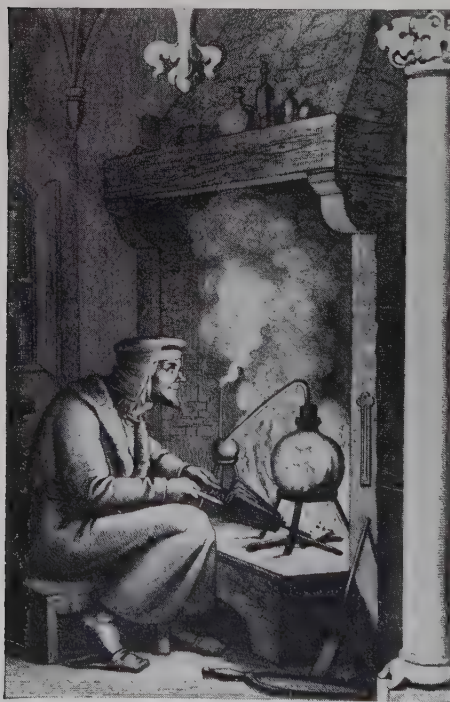
CHAPTER 16

ORGANIC CHEMISTRY

AT the beginning of the nineteenth century the great Swedish chemist, Berzelius, placed the compounds of which living things are made, in a class by themselves. These, he said, could be made only through the agency of a vital force which could operate nowhere but in the living cell; certainly not in chemists' test tubes. Well enough to talk of the synthesis of simple inorganic substances in the laboratory, but the more complex and delicate materials of life

were beyond a synthesis directed by the mind of man. Berzelius was a giant among his fellow chemists and his ideas carried great weight. But no sooner had his dictum of the operation of a vital force been generally accepted, when one of his own pupils, Friederich Wöhler, working in his laboratory at Giessen, succeeded in preparing urea from inorganic materials (1828). The bridge connecting the inorganic with the organic had been crossed for the first time in the laboratory. Today thousands of tons of organic chemicals, which never saw the interior of a living cell, are being manufactured from inorganic matter.

Every organic compound contains the element carbon. Indeed, it is because of a unique property of this element that such a multiplicity of organic compounds exists. A far greater number of carbon compounds is known than that of all the other elements put together. This unique property is the ability of carbon atoms to join directly with one another to form long chains and even rings which are the backbones of the organic molecules. Over 300,000 organic compounds are known, most of which do not exist in nature but are the products of the organic chemist's genius for synthesis. He is, in a sense, a molecular architect. He draws "blueprints" of the molecules of naturally occurring substances which show the location of every atom in its molecule and then proceeds to build synthetic molecules in his laboratory to the specifications of his plans. If his picture of molecular structure is cor-



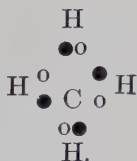
Black Star from the Bettmann Archive

Fig. 1. An artist's conception of Faust, the hero of Goethe's drama, attempting to create organic substances in the form of man through chemistry

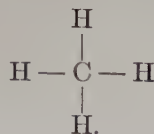
rect, the synthetic substance is identical with the natural product. Or he may draw the design of a new molecule whose properties, he thinks, will make it more useful for a certain purpose than those of any known substance. These new molecules are then synthesized and many times his predictions come true.

To obtain some idea of the molecular complexity of organic substances we must first consider the "blueprints," or, more properly, the structural formulae, of their molecules.

The carbon atom consists of a nucleus of six unit positive charges about which are six planetary electrons, two of which are in the inner shell, while the remaining four are in the outer. In this so-called valency shell there are, therefore, four electrons and four empty spaces (see p. 233) which the atom attempts to fill with electrons from the atoms with which it combines. For example, the molecule of the simplest compound of carbon and hydrogen, methane, is made up of one carbon atom and of four hydrogen atoms. Each hydrogen atom is composed of a nucleus of one proton and of one planetary electron. These four atoms bring one electron each to fill the four empty spaces in the carbon atom. At the same time each hydrogen atom shares its own electron and one from the carbon atom and so fills its only shell with its full quota of two electrons. We may picture the methane molecule as follows:



Each shared pair of electrons constitutes a valence bond holding atoms together. If we draw a line in place of each shared electron-pair, we may further simplify the formula:



In more complex structural formulae the same fundamental rules apply. Every carbon atom must have four valence bonds and every hydrogen atom only one. Every oxygen atom with six electrons in its valency shell has two spaces to fill and hence two valence bonds, and so on.

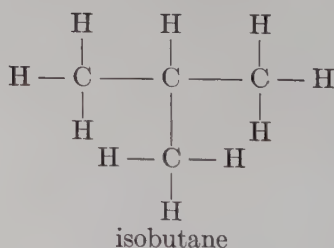
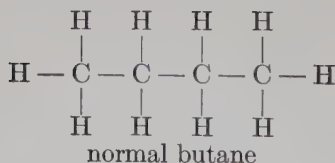
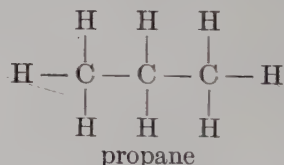
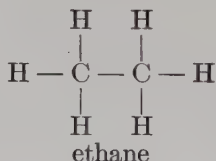
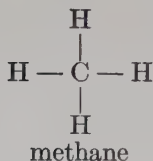
THE HYDROCARBONS

The simplest general class of organic substances are the hydrocarbons, which are compounds of the elements hydrogen and carbon only. One may well wonder why several hundred such compounds exist when other pairs of elements form at the most only a few compounds. For example, there are five different compounds of nitrogen and oxygen and this number is larger than the rule. However, since carbon atoms join with one another directly to form chains and rings, such a large number of hydrocarbons is easily possible. For convenience, the hydrocarbons are classified as chain, or aliphatic, and as ring, or aromatic.

By far the majority of these chain hydrocarbons are found in nature in petroleum oil. In fact, this valuable natural resource is little more than a grand mixture of gaseous, liquid, and even solid hydrocarbons. In order that we may be able to appreciate the

significance of the structural formulae of important natural substances, it will be worth while to consider the formulae of some of the simpler of these hydrocarbons. The formula for methane has been placed before you already. This hydrocarbon, incidentally, makes up almost 99 per cent of natural gas, an important fuel. It is also found, wherever vegetation is decaying, as marsh-gas and as the "fire-damp" of coal mines, where it is justly feared because it forms explosive mixtures with air.

The nearest relatives to methane are all members of the paraffin series of aliphatic hydrocarbons. Here are the formulae and names of the first few members of this series:



All of these are gases at ordinary temperature and pressure and come out of solution when petroleum is distilled in the process of refining. It is interesting to note that there are two butanes, both of whose molecules are composed of the same number of carbon and of hydrogen atoms, but with these atoms differently joined together in the molecular structure. These are the molecules of different substances.

Such compounds, whose molecular composition is the same but whose molecular structures are different, are called isomers. Their molecules are like different houses built of the same materials, but to the specifications of different blueprints.

PETROLEUM PRODUCTS

The molecules of the higher hydrocarbons of this series are made up of greater numbers of hydrogen and carbon atoms. The carbon chain "backbones" are longer and in many cases branched. Those molecules with from five to ten carbon atoms are the low-boiling liquids which, mixed together, make up gasoline. Mixtures of hydrocarbons of progressively higher boil-

ing points are well known as kerosene, gas-oil, and the various lubricating oils. From the latter, solid hydrocarbons, better known as "paraffin," are frozen out of solution. We have mentioned in an earlier chapter how the commercial products are obtained as separate fractions when petroleum is distilled.

The gas-oil fraction comprises somewhat over 40 per cent of the

products, whereas gasoline makes up only about 25 per cent. Since the latter is in far greater demand, the method by which gas-oil is subsequently converted into gasoline is of great economic importance. The petroleum hydrocarbons distil under atmospheric pressure without decomposition; that is, their molecules are stable at the temperatures at which they boil. If, however, the gas-oil fraction is heated under pressure, the boiling points of its constituent hydrocarbons are raised. They may thus be heated—without boiling away—to temperatures so far above their normal boiling points that their molecules break down into simpler ones, many of which correspond to gasoline hydrocarbons. This is the important cracking process by which the number of gallons of gasoline obtainable from a given amount of crude oil has been doubled. This represents an important saving of a valuable and definitely limited natural resource.

REFINERY GASES

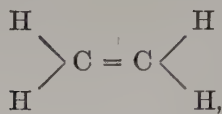
The fracture of a gas-oil molecule in the cracking process does not always occur in the middle of the carbon chain and, therefore, does not invariably produce two gasoline molecules. Frequently, ends of molecules are lopped off and these make up a relatively large volume of gas. In the United States, about 940,000,000 cubic feet, or 14,000,000 tons, per year, of refinery gases are formed. Some of this gas is purposely dissolved in gasoline for winter use, since its high volatility makes starting easier. In the summertime, however, the presence of such gases is undesirable, for they tend to come out of solution before reaching the carburetor and cause a "vapor-lock" which stalls the engine.



Fig. 2. Natural gasoline is processed in plants such as the one above from natural gases which accompany the crude oil from the well. About six per cent of automobile motor fuel is natural gasoline, which adds materially to the quick-starting properties of gasoline

One of these gases, isobutylene, each molecule of which contains four carbon atoms, is polymerized into the highest grade of aviation gasoline. Its molecules combine in pairs to form the molecules of eight carbon atoms each of this gasoline. The conversion of the energy given out in the combustion of this gasoline into mechanical energy is so efficient that far less energy is lost as heat than is the case with regular gasoline. Aviation motors with less cumbersome cooling systems may be used, which therefore develop greater speeds and can travel further on the same number of gallons—especially important in time of war.

Among the hydrocarbons in refinery gases are several with double valence bonds between pairs of carbon atoms. The simplest of these is ethylene,



and its history is quite interesting. About twenty years ago a florist in Chicago noticed that whenever he placed carnations in a certain corner of his greenhouse they curled up their petals and went to sleep. Puzzled by this strange behavior, he called on Dr. William Crocker, a botanist, for assistance. Together they investigated

the fatal corner and finally located a leak in a gas line which was causing the damage. Now illuminating gas is a mixture of several components, each of which was tried in turn on the carnations. Ethylene proved to be the offender. Although its conduct in this connection was decidedly bad, in other respects it has proved useful in many fields.

In 1922, Luckhardt and Carter, of the University of Chicago, discovered the usefulness of ethylene as a general anesthetic. As in the case of the carnations, rats and human beings go to sleep in 80 per cent ethylene. Its anesthesia is as deep as that produced by ether and is without the unpleasant after effects which accompany the use of the latter.

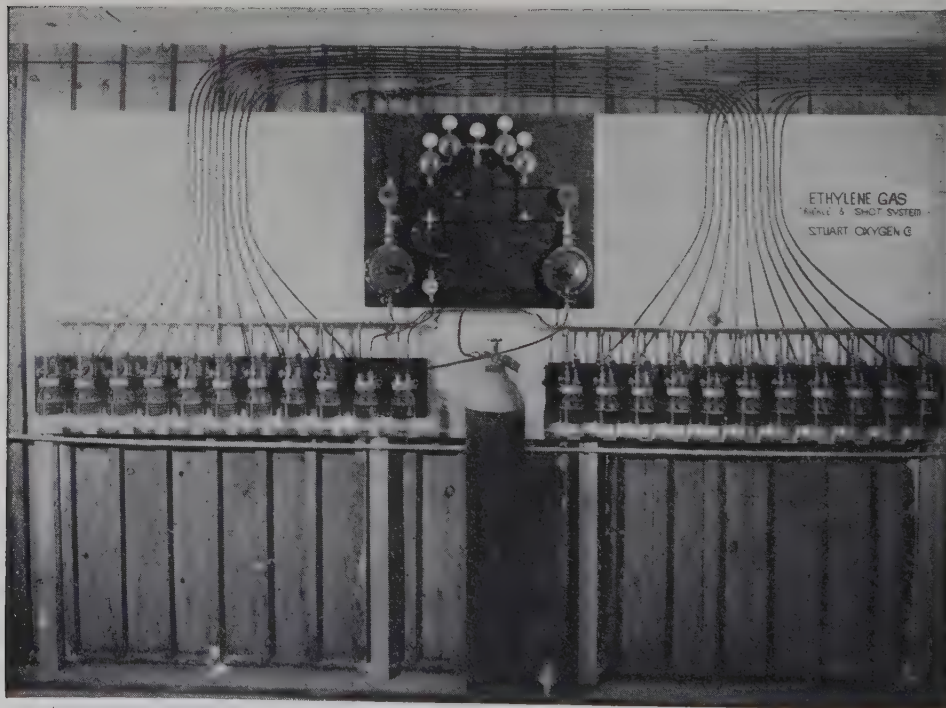


Fig. 3. An ethylene-gas distributing panel of the type used to control the treatment of the air to which citrus fruit is subjected before shipment



Firestone Tire & Rubber Co.

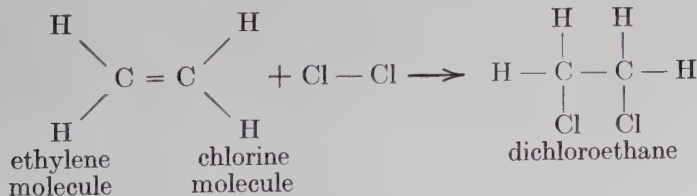
Fig. 4. Rolls like this are part of the mixing mill which, by its masticating action, reduces synthetic rubber to a plastic mass. When the rubber has reached this condition the many chemicals and pigments necessary to the finished product are added

Citrus fruits are said to be ripe before they develop the full color which housewives associate with ripe fruit. If they are picked only after this color develops and are then shipped across the country, spoilage is high. Ethylene gas has the useful property of developing the full color of oranges and lemons which have been shipped ripe but green. In as low a concentration as 1 part of ethylene in 3,000 parts air, 25 cubic feet of this gas can color a carload of

oranges in five days to the tint of tree-ripened oranges.

UNSATURATED HYDROCARBONS

A double valence bond is a sign of reactivity in an organic molecule. Only one bond is needed to hold two atoms together and the second bond is pure luxury, much as having a second man using the same shovel. The second bond opens readily to add other atoms to the molecule. Thus ethylene adds two chlorine atoms:

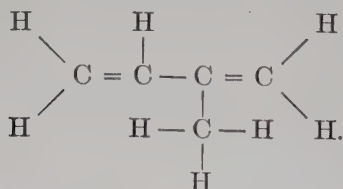


In a similar manner other atoms may be added and many compounds of great commercial importance manufactured; for example, ethylene glycol, or "Prestone," the antifreeze for automobile radiators.

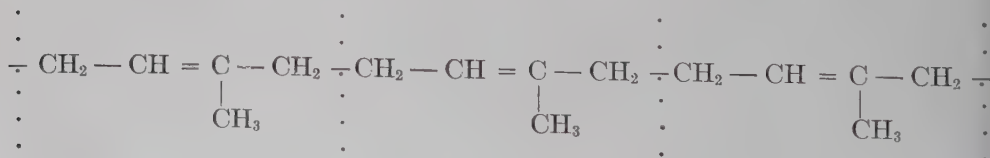
Compounds like ethylene whose molecules contain more than one valence bond between a pair of adjacent carbon atoms are said to be unsaturated.

Unsaturated compounds will not only add other atoms but frequently two or more molecules of the same kind can be made to join together by the opening of the second valence bond of the unsaturated linkages. This process is called polymerization and by its use many extremely useful products have appeared in recent years. The conversion of isobutylene into aviation gasoline is one of them.

Natural rubber is a polymer of the unsaturated hydrocarbon, isoprene:



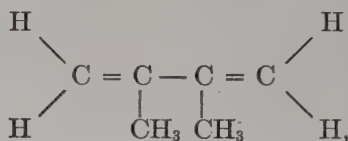
This relatively simple molecule combines with itself to form a giant molecule consisting of a long chain of isoprene units:



The above formula represents but a small portion of the giant molecule which is made up of about 2,200 isoprene units.

SYNTHETIC RUBBER

During World War I Germany suffered acutely from the lack of natural rubber. Under these difficult conditions she succeeded in synthesizing as much as 4,000,000 pounds a year of artificial rubber derived from dimethyl butadiene,

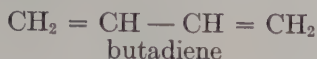


which could then be more readily synthesized than isoprene. The cost of this artificial rubber was high but the blockade made the synthesis of a rubber substitute imperative.

More recently the I. G. Farbenindustrie developed a series of products known as the Buna rubbers. The Firestone and Goodrich Companies in the United States have also developed synthetic rubber materials. These are in many respects superior to natural rubber, although as yet more expensive. The useful properties of natural rubber are, as everyone knows, its elasticity and mechanical strength. Against it are its too great chemical activity which results in a gradual loss of its elasticity and strength, its low heat stability, and its susceptibility to acids and petroleum oils. These new

synthetic products are superior to rubber in the latter respects. Most of them are copolymers; that is, they are giant molecules built up from two

different basic substances. These presumably alternate in the chain of the giant molecule. For example, Perbunan is a copolymer of butadiene and acrylonitrile:



There is some evidence that the superior mechanical strength of these copolymer rubbers is due to cross-valence bonding between adjacent parallel chains of atoms. This does not seem to occur in natural rubber. The raw materials from which these rubbers are synthesized are mainly by-products of the petroleum industry.

NEOPRENE

Another synthetic rubber, Neoprene, was developed and is being

synthesized in this country from such simple inorganic materials as limestone (CaCO_3), coke (C), and water and salt (NaCl). It may be of some interest to follow the course of this



synthesis. Limestone, heated in limekilns is converted into lime (CaO) and carbon dioxide (CO_2). Lime is then heated with coke in an electric furnace and is changed to calcium carbide (CaC_2) which is converted into acetylene upon treatment with water. The molecules of this gaseous hydrocarbon have a triple bond between pairs of carbon atoms. Below is the chemical formula:

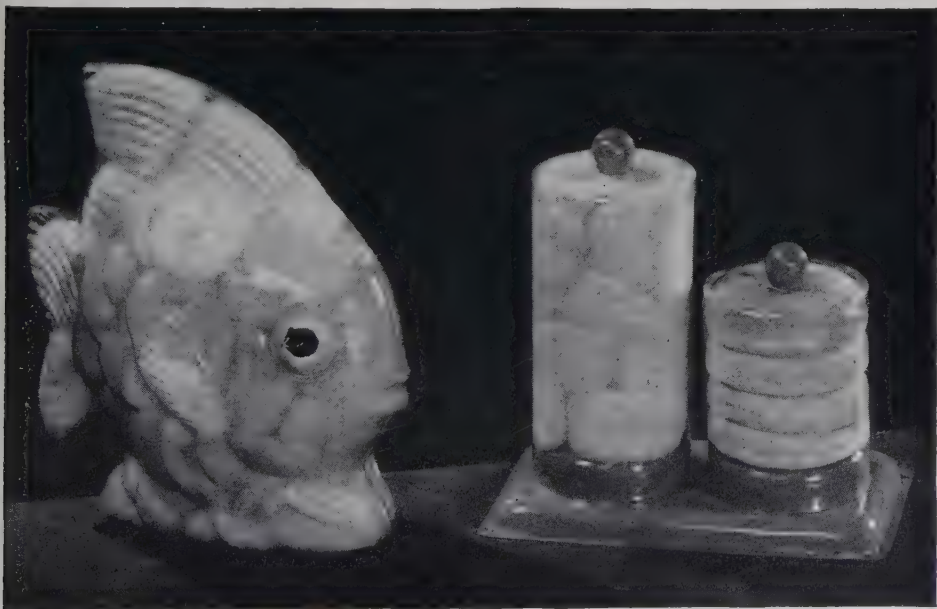
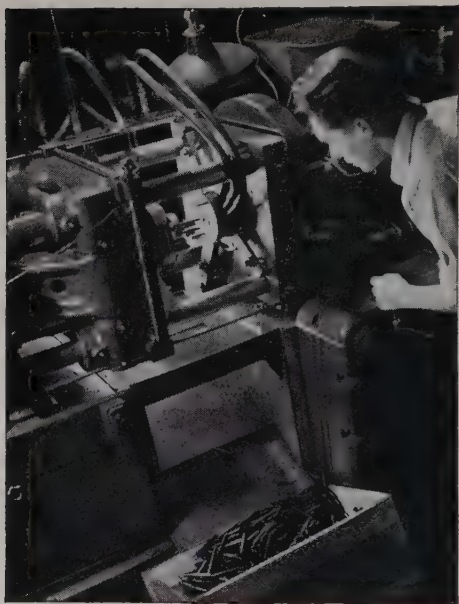


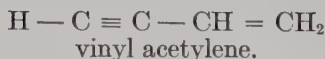
Fig. 5. One of the newer plastics is vinylite, here used to make an attractive waterproof container for face powder and powder puffs. The adaptability of plastics is evidenced by the fact that women's shoes are also made from vinylite



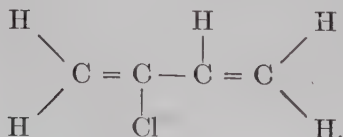
Bakelite Corp.

Fig. 6. Bakelite was among the first of the plastics to achieve wide use. Here we see a machine which molds the plastic to a definite shape

which indicates great unsaturation. Two such molecules are then united to form the molecule of vinyl acetylene:



Finally the hydrogen and chlorine atoms of hydrochloric acid (HCl), derived from salt, are added to the triple bond and chloroprene results:

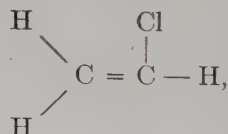


The similarity of this molecule to that of isoprene is very marked, since the

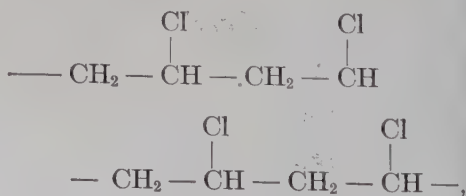
chlorine atom of chloroprene takes the place of the methyl group (CH_3) of isoprene. In a similar fashion chloroprene polymerizes to neoprene rubber. This superior rubber, manufactured in this country in ever-increasing amounts, is a product of exclusively American research.

PLASTICS

One of the most interesting developments of this century has been the manufacture of synthetic plastic materials. The variety of form and color of these plastics is familiar to the public in fountain pens, umbrella handles, jewelry, etc. The high electrical insulation offered by bakelite, the first of the commercial synthetic plastics, makes it useful for distributor heads of automobile engines, electric shavers, irons, and other heat-exposed articles. All these plastics are polymers or copolymers of relatively simple substances. Vinyl chloride,

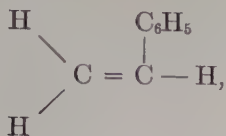


for example, polymerizes to a chain molecule of which the following is a portion:



and a copolymer of vinyl chloride and vinyl acetate is a beautiful, transpar-

ent plastic sold as Vinylite. Styrene, or vinyl benzene,



similarly polymerizes to form a polystyrene plastic. These synthetic plastics are used not only for the manufacture of small articles but also for furniture, as well as for wall panels and other large architectural parts. Recently, aeronautical engineers have begun to use plastics for airplane wings and bodies. A transparent airplane offers unique wartime possibilities.

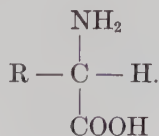
PROTEINS

Great as is the importance of giant molecules to modern civilization, their greatest interest to us lies in the fact that such molecules play a fundamental part in life itself. Living cells are made up of many different substances; carbohydrates, lipids, salts, nucleic acids, and—invariably—proteins. Every cell, from those which are complete organisms in themselves to those which are a part of an organ in an animal, may contain many of the same substances, but its proteins are characteristically its own. Dog proteins are not those of a horse nor those of a man. Indeed, foreign proteins are seldom received with open arms by an organism. The venom of the cobra is merely a protein but in the blood stream of man it acts as a deadly poison. Since these proteins are so characteristic of each different form of life, a knowledge of their structure would be a long step along

the path leading to the ultimate explanation of life itself.

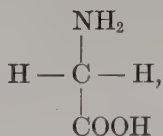
The problem, however, is exceedingly difficult. It would seem as if nature had erected every barrier to its solution. First of all a chemist must be certain that he has a pure substance before he can attempt to determine its molecular structure. Proteins are usually associated with many other substances so that the usual methods of separating mixtures cannot be employed. This is because proteins are extremely sensitive, as indeed they must be to react to the changes in environment which stimulate living organisms. Once this difficult operation has been accomplished and a pure protein has been isolated, the task has only just begun.

Proteins are compounds of the elements, carbon, hydrogen, oxygen, nitrogen, sulphur, and, in some cases, phosphorus. However, this knowledge tells us as little about the structure of proteins as the fact that an automobile is composed of iron, brass, rubber, glass, etc., tells us of the structure of a motorcar. The great German chemist, Emil Fischer, succeeded in breaking down protein molecules under mild conditions into compounds belonging to a class of substances called amino acids. All of their molecules contain the amino group ($-\text{NH}_2$) and the acid group ($-\text{COOH}$) attached to the same carbon atom:

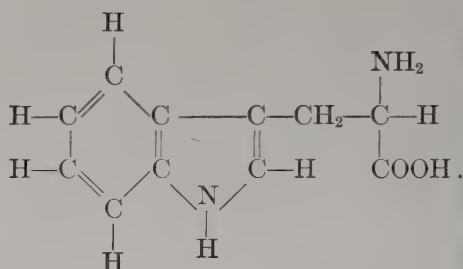
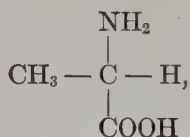


In this formula R stands for either a hydrogen atom in the case of the

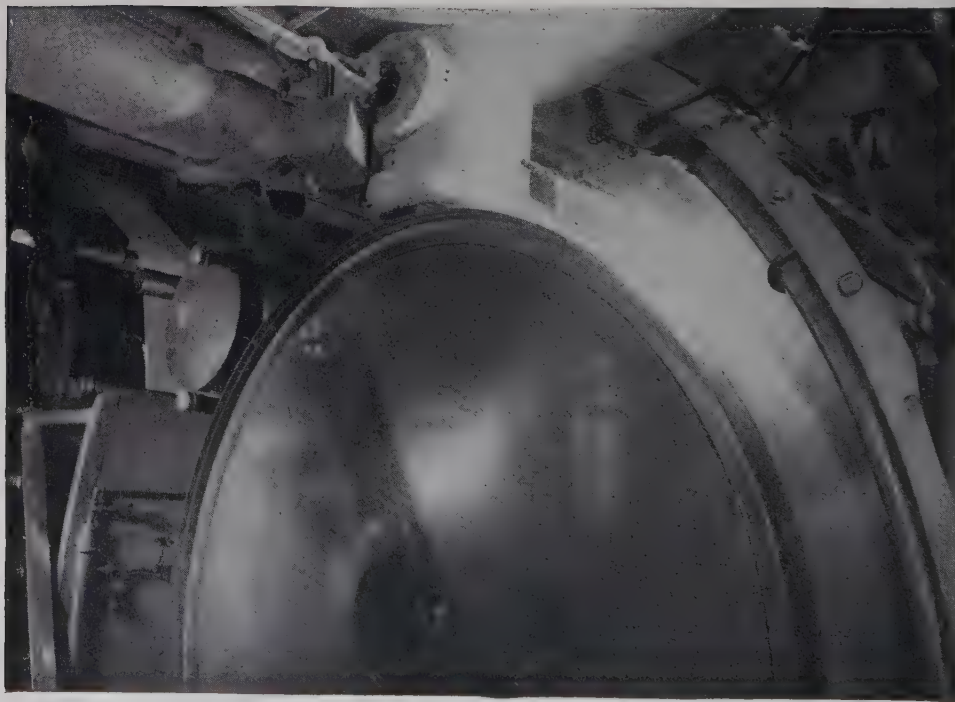
simplest of all amino acids, glycine, to tryptophane,



or for some group of atoms in each of the 21 other different amino acids found as products of protein decomposition. These vary in complexity from alanine,



Practically every one of the 22 are to be found among the decomposition products of every protein so that these are the building blocks of protein molecules.



Du Pont Co.

Fig. 7. Molten Nylon at an early stage in its manufacture is extruded on this huge casting wheel and quickly sprayed with water. This solidifies it into a strip resembling ivory. In later operations it is chopped, melted, and extruded again as filaments

PROTEINS FROM AMINO ACIDS

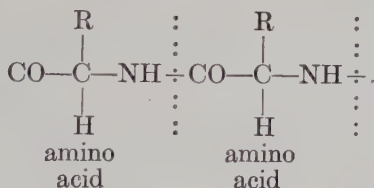
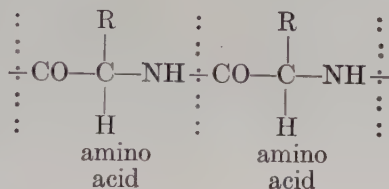
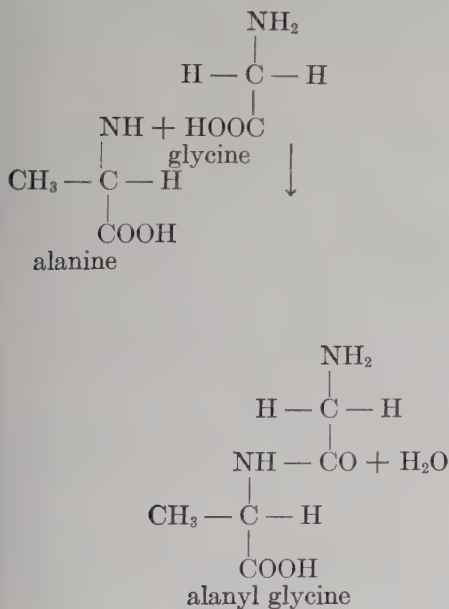
How are these amino acids linked together in the protein molecule? Amino groups have the property of combining with acid groups in a reaction which involves the elimination of water:

longer chain. By uniting from 7 to 19 amino acid molecules in this way, Emil Fischer succeeded in synthesizing substances which had many of the properties of the simpler natural proteins. The evidence seems, therefore, quite conclusive that all protein



It seemed logical to Emil Fischer to postulate that amino acids are combined in this way in proteins. Thus aniline and glycine might combine as follows:

molecules have the following skeletal structure:

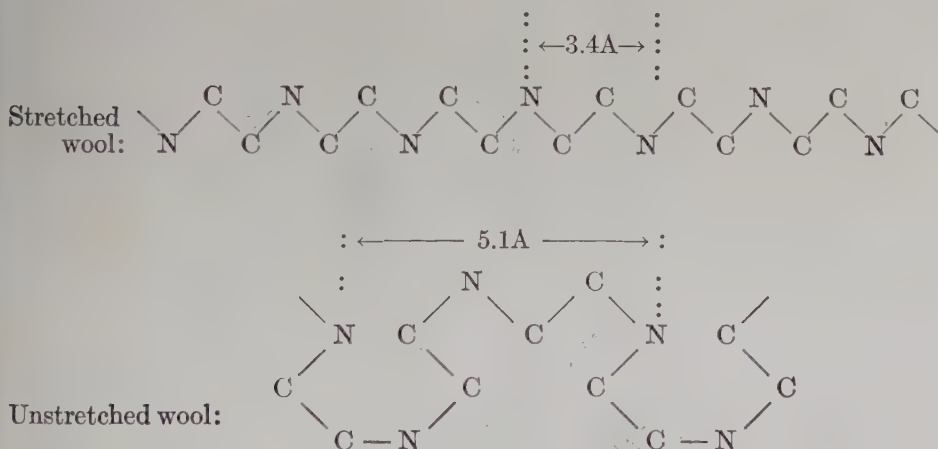


This "double-molecule" still has an amino and an acid group and can add other amino acids to form a

Of course, to be able to construct the complete formula of the molecule of a given natural protein, we must know not only the number of each kind of amino acid in the molecule but also the order in which they are linked together in the chain. Just as many different parades may be formed of the same number of unit organizations, so almost countless different protein molecules can be built of the same amino acids. We are still

The CO groups are 3.5A apart, and the CH₃ groups of the alanine, 7A.

Wool fibers, when steamed, can be stretched to nearly twice their normal length, although upon drying they shrink again. An X-ray study of stretched wool shows the same repetition of similar groups at intervals of 3.4A as is found in silk. However, the repetition occurs at intervals of 5.1A in the unstretched molecules. This apparent paradox is explained in the following diagram by assuming that the chain in the unstretched molecule folds back on itself:



By far the greater number of proteins are not fibrous like wool and silk but are globular like egg albumen. It seems highly probable that in such protein molecules the chains are yet more highly folded into a hexagonal cellular structure.

MOLECULAR WEIGHT OF PROTEINS

The methods by which the relative weights of molecules of ordinary size are determined cannot be applied to the giant molecules like those of the

proteins. However, a method has been developed by Svedberg in which centrifugal force is used to separate particles of different weight. When particles are suspended in a liquid, the rate at which they settle due to gravity is largely determined by their weight. Large pebbles sink faster than tiny silt grains when suspended in water. Molecules, however, even those of proteins, are so light and in such constant thermal motion that their rate of settling due to gravity alone is almost infinitely slow. By spinning such suspensions in an ultracentrifuge,

revolving at extremely high speeds, a force of several thousand times that of gravity is exerted and the giant molecules settle at measurable rates. By this means Svedberg calculated that the molecular weight of the simplest proteins was of the order of 17,000 times the weight of the hydrogen atom. Others were twice, four, and even eight times as heavy. Some had molecular weights in the millions, in which cases their dimensions are not far from the limit of microscopic



Rockefeller Foundation

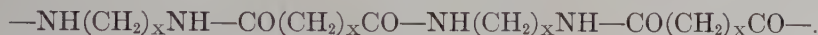
Fig. 9. Among the most spectacular contributions of modern science has been breaking up of the atom, formerly believed indivisible. This is a high voltage "atom smasher"

visibility. The average protein is made up of about 290 amino acid units.

The synthesis of a protein like wool on a commercial scale is still beyond the dreams of even such optimists as the organic chemists. Recently, however, an artificial fiber called Nylon has been synthesized on a commercial scale. This is a copolymer of a diamine and a diacid,



which combine to form a giant molecule in which the linkages are of the same type as those in proteins:



Since the cost of silk from Japan goes as high as \$4.00 per pound, it is not at all unlikely that in this country Nylon may replace the natural fiber to a large extent.

VIRUSES

The bacteria, many of which cause disease, are one-celled organisms which are visible under the microscope. These cells have a characteristic structure by which they may be recognized. All are large enough to contain many thousands of protein molecules. Such bacteria have the property—in common with all other living organisms—of building up the materials of their structure from other substances. They also have the ability to reproduce. Bacteria may be filtered from the medium in which they are suspended, by a porous earthenware of fine texture. Certain bacteria are

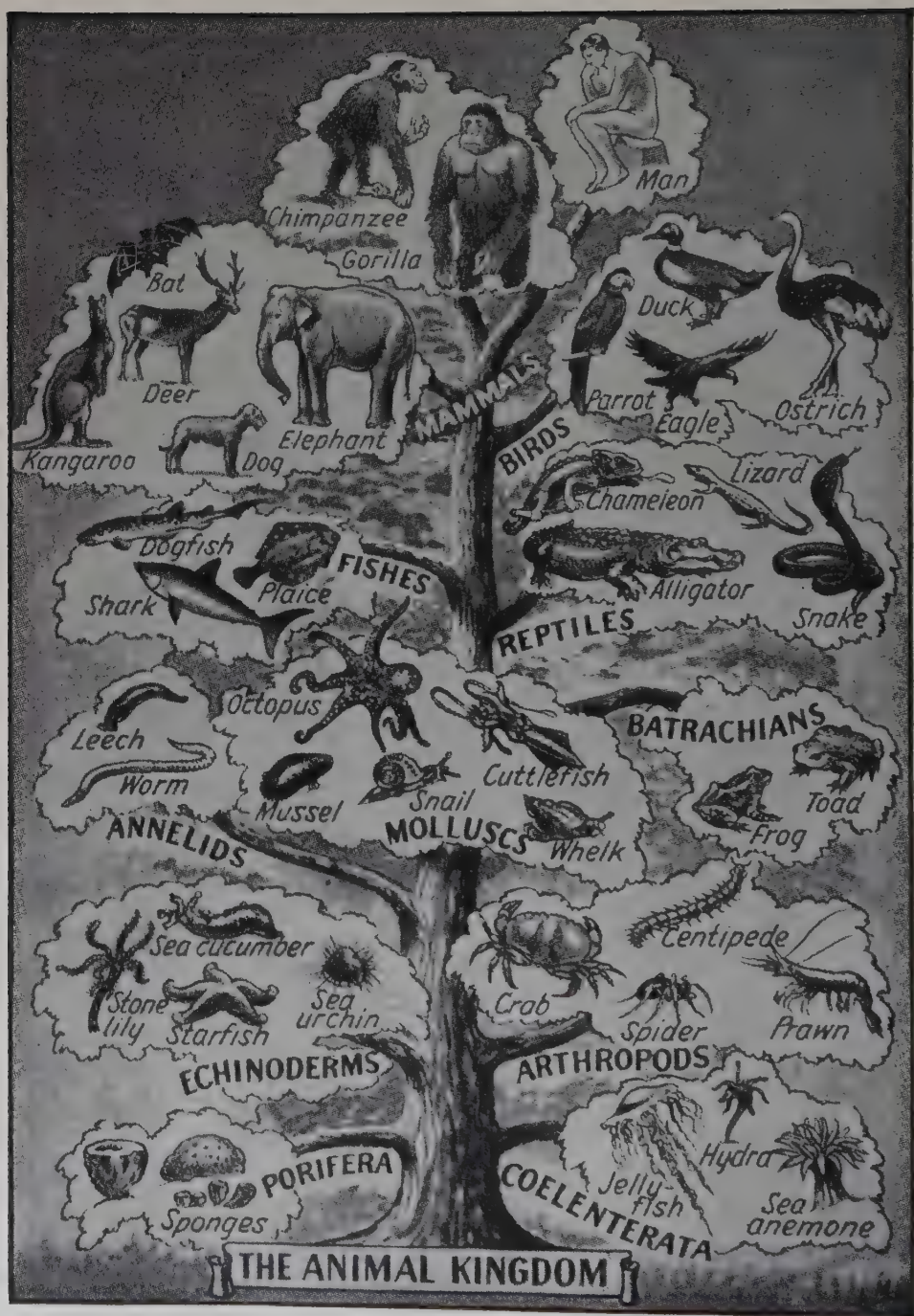
responsible for such diseases as typhoid, diphtheria, tuberculosis, and cholera.

There are other infectious diseases, however, for which bacteria are not responsible; these include smallpox, measles, infantile paralysis, mumps, and the common cold in human beings, the foot-and-mouth disease of cattle, distemper in dogs, and the mosaic disease of tobacco plants. The

saliva of a cow, suffering from foot-and-mouth disease, may be strained through filters fine enough to remove

bacteria completely, nevertheless, it will still cause the disease in other cattle. Similarly with the other diseases mentioned, the living agent which causes the disease is far smaller than are bacteria. Such agents have been called viruses. W. M. Stanley, of the Rockefeller Institute, has recently succeeded in growing crystals of a pure protein from the juice of plants infected with the tobacco-mosaic virus. These crystals not only retain the property of causing the disease in tobacco plants but are also able to assimilate materials which contain the necessary amino acids and build up from them molecules like themselves. Here, then, is a crystalline material, with molecules of a single protein as its sole structure unit, which possesses the necessary properties to be classed as living. The gap between the animate and the inanimate has been decreased.

Note: The illustrations appearing in this section on pages 233; 268; 273, Fig. 29; 305; 314, Fig. 8; 317, Figs. 13 and 14 are from "An Introduction to Chemistry" by John A. Timm, published by the McGraw-Hill Book Company.



An artist's impression of the story of evolution, showing how man, like every other form of both plant and animal life, is descended from common ancestors

SECTION IV

THE MARVEL OF LIVING THINGS

CHAPTER 17—THE NATURE OF LIFE

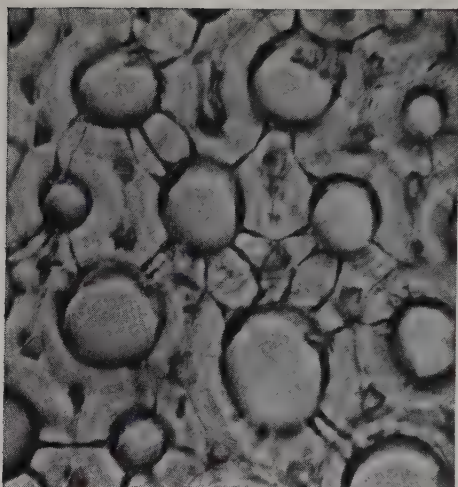
LIFE and all that pertains to it constitutes the organic as contrasted with the inorganic, or non-living, aspect of our universe, and all the living things, either animal or plant, are known as organisms. The study of life is the concern of the biologist, and in the field of biology there is no problem greater than that concerned with the nature of life itself.

It was once thought that living things possessed energy which was lacking in the inanimate, but with a clearer understanding of matter it has become apparent that it never exists free from energy, in fact it may be nothing more than a manifestation of energy itself. With this conception of matter there has come a realization that the separation between the animate and the inanimate is not so sharply marked or so wide as was formerly believed. There is no doubt that organic matter possesses capacities which are lacking in the inorganic, and especially that the energy of vital processes is different in certain aspects from the energy displayed in the inanimate, yet such laws as the conservation of matter and the conservation of energy apply to both alike, and the exact distinction between the living and the non-living is not known.

It is known that all living organisms are characterized by the presence of a substance called protoplasm. By chemical analysis this substance is known to be composed

largely of carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus, with such occasional constituents as calcium, magnesium, sodium, and iron. Although the proportion of these constituents can be very accurately determined, the chemist has not been successful in synthesizing protoplasm in the laboratory, nor has he been able to determine why it possesses that property which we call "life." He knows only that it is a gelatinlike or emulsionlike substance of the type which he classifies as a colloid, with a very complex arrangement of its atoms in large molecular systems, and he feels quite certain that its peculiar properties are in part due to its intricate structure. The basis of this complicated molecular arrangement is the carbon atom which has a peculiar capacity for combination with many different elements in a number of ways, and organic chemistry, which has contributed very largely to a better understanding of living processes and their products, is the chemistry of the carbon compounds.

The great obstacle to a better understanding of the real nature of protoplasm is the fact that any analytic process to which it is subjected results in the destruction of its living properties. The chemist can analyze *dead* protoplasm, but he cannot determine just what changes take place when life disappears. However, although neither the biologist nor the



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Fig. 1. Protoplasm is a jelly-like, colorless material which exists in many modifications. The cells shown here are made up of protoplasm and are "floating" in yet another form of protoplasm. The connecting canals between the cells can be clearly seen

chemist can tell us just what protoplasm is, it is recognized that it is the medium of life itself; stimulate it and some vital process occurs; destroy it and life ceases to exist. Its most distinctive characteristic is its ability to continue its own existence and activity, its capacity to grow and reproduce itself by taking in food substances and incorporating them into itself to form new protoplasm.

ORIGIN OF LIFE

Just as no one knows exactly what life is, so also are we in complete ignorance as to where, when, or in what form, life was first manifested on the face of the earth, whether it originated in some one form at one time and place, or in several forms at different localities and at various times. There is no known geological

record of the event, nor is it likely that one exists, since, whatever the nature of the first organisms, they were presumably of too simple a structure to be readily preserved as fossils. Furthermore, the occurrence must have taken place in a past so remote that it may even antedate the oldest known geologic formations. There has been much speculation in regard to this problem, but as yet no convincing solution has been presented. From the scientific approach there are only two possible answers—that life developed from inorganic substance on the surface of this planet, or that it was introduced from some other heavenly body, probably from some other planet in our solar system.

The latter idea was first proposed by a Swedish physicist, Arrhenius, and, although it is a bit fanciful, it can be said to lie within the realm of the possible. Considering that some organisms, especially in certain dormant stages, can retain their vitality during very long periods under extreme conditions of both high or low temperature, and that they can undergo severe desiccation, it is conceivable that some such organism or organisms, perhaps of microscopic size, might have drifted through outer space, propelled perhaps by light waves, or that they might have been introduced on meteoric material. The greatest difficulty with this theory is that essentially it is not a solution of the problem at all, but simply transfers it to another portion of the universe. As a theory it is susceptible of neither proof nor disproof, but the fact should be taken into consideration that most astronomers are rather skeptical of the presence of life, as we know it, on any planet except our

own. As to other solar systems with planets which might have served as a source of life, none are known, but, if they do exist, they must be so far distant that any germs of life coming from them to the earth must have possessed a capacity to withstand extremely severe conditions during many years of wandering.

A more reasonable explanation, and one which is more sound from the scientific viewpoint, is that, under conditions peculiar to some primitive stage in the development of the earth, inorganic substances containing carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, and various mineral elements chanced to combine chemically to form protoplasm. Since one of the properties of protoplasm is its ability to renew its own substance, once life was started it could be continuous. If such a process could occur once under primeval conditions, there would appear to be no reason why it should not be repeated many times for as long as the conditions remained favorable. If life were repeatedly created, there would be no reason for it taking the same form each time, therefore the first life may have been manifested in various shapes. The conditions necessary for such a process to operate are not known.

SPONTANEOUS GENERATION

Whatever the process may have been which resulted in the first life, it appears to have been restricted to primeval times. The modern dictum of biology is *omne vivum ex vivo*, that all life originates from pre-existing life, but down to the middle of the last century it was thought, even by many biologists, that living creatures could be generated spontaneously, and that many of them did

arise in that manner under natural conditions. Aristotle taught that many of the simplest forms of life arose from mud, slime, or putrid matter, and in his classification of the animal kingdom one group was composed of such animals. Virgil, the Roman poet, describes in all seriousness a method of generating a swarm of bees by beating the entrails from a bull and surrounding the carcass with certain kinds of flowers in an open pen. Up until late in the seventeenth century, spontaneous generation was quite universally accepted. It was during the latter century that one author reproved another for doubting this phenomenon in the following words: "So may we doubt whether in cheese and timber, worms are generated; or if beetles and wasps, in cow-dung; or if butterflies, locusts, shell-fish, snails, eels, and such like be procreated of putrified matter which is apt to receive the form of that creature to which it is by formative power disposed. To question this is to question reason, sense and experience. If he doubts of this let him go to Egypt, and there he will find the fields swarming with mice, begot of the mud of the Nylus, to the great calamity of the inhabitants."

In 1688 an Italian, Francesco Redi, by a simple experiment proved that maggots and flies were not generated in decaying meat. Using several jars, he exposed meat in some, but prevented the flies from having access to others by covers of parchment. The meat spoiled in all of the jars, but only in those open to the flies did maggots appear. Furthermore, he found that the flies laid eggs on the parchment covers, and that maggots hatched from these eggs. This was the first of a number of experiments by Redi and

other workers which finally resulted in banishing from the minds of scientific men any belief in the spontaneous origin of forms of life large enough to be visible to the unaided eye, but when the microscope came into use, at about the same time, the question reappeared in a new aspect. The world of microscopic life, now brought to man's attention for the first time, became the center of a similar controversy. Because of the greater difficulty in excluding microscopic life from the media used in such experiments, especially before the modern methods of sterilization had been perfected, this controversy continued intermittently through more than a century, and it finally remained for the renowned French scientist, Louis Pasteur, to bring the argument to a close. In 1864, he demonstrated conclusively, by a carefully controlled series of experiments, that even microorganisms are not spontaneously generated.

In some of the simplest forms of life even this membrane is lacking. The general protoplasm of the cell is usually semifluid, viscid, and colorless, and is referred to as the *cytoplasm*. It may fill the whole cell, except for a few contained water drops called vacuoles, or these vacuoles may have increased in size and coalesced to such an extent that they occupy all of the interior of the cell, in which case the cytoplasm remains as a thin layer lining the cell wall. Vacuoles consist of water with various food and waste products in solution.

Imbedded in the cytoplasm of most normal cells is a protoplasmic structure known as the *nucleus*. Usually there is only one to a cell, but occasionally cells are multinucleate. This structure is the most important and the most complex part of the cell; its principal role appears to be reproductive, but there is considerable evidence that it is the center and the motivating agency in nearly all cell

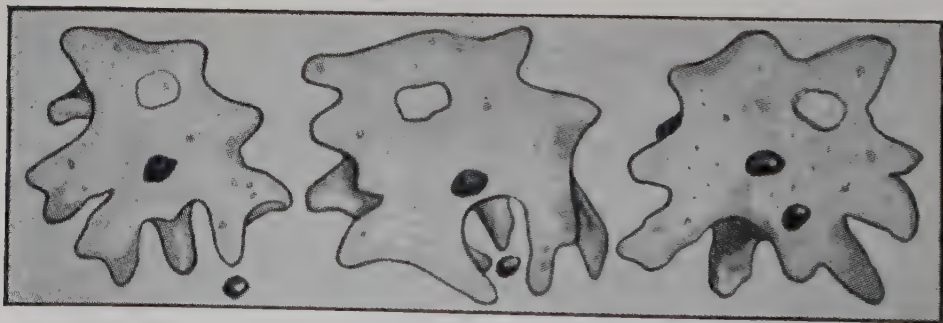
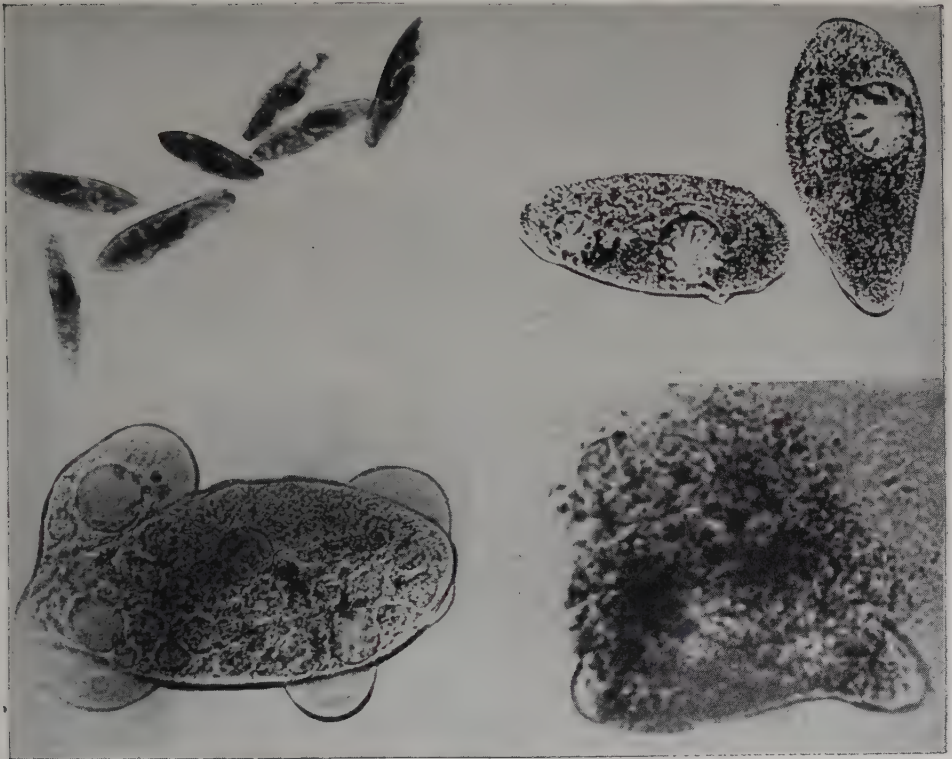


Fig. 2. The amoeba, a simple unicellular organism found in ponds, feeds by engulfing food

THE CELL

In all animals and plants the protoplasm that is the basis of life is organized into units of structure called cells, and each cell is essentially a mass of protoplasm contained within a membrane known as the cell wall.

activity. A fragment of a cell which includes a nucleus will continue to live, if kept under proper conditions, and will even form other cells, but a denucleated cell cannot reproduce, nor can it carry on any of its functions in a normal manner. In the division



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Fig. 3. The death of a paramecium through exposure to ultra-violet radiation. In the picture at top left are a few normal paramecia. At right two of the paramecia have been exposed to the rays for 30 seconds and distension is obvious. Lower left the distension increases until the paramecium (lower right) becomes too big for its cell wall and bursts

of a cell to form two cells, the nucleus divides first. The part played by the nucleus in determining the characteristics of an organism, and in passing on these characteristics will be described in Chapter 24.

Another type of protoplasmic structure occurring in the cytoplasm of many cells, especially in plants but also in some of the one-celled animals, is the *plastid*. Plastids are usually pigment bearers; in the green plants they contain the pigment chlorophyll, the importance of which will be discussed in the following chapter, and in the

bright flowers of reddish or orange hue, or in red fruits such as red pepper, the color is usually due to pigments borne in plastids. Another type of plastid found in plants is colorless, yet these plastids play important roles in functioning as centers of starch formation. In addition, there are other structures found within the cytoplasm of many cells, but the nature of most of them is not very well understood, their importance in the life of the cell is not known, and they are of little interest to anyone except the specialist in the study of the cell.

The cell wall is not composed of protoplasm. In plants it is usually, although not always, made up of cellulose. When first formed, it is a very delicate membrane, largely composed of pectin, but, as the cell ages, its wall is usually thickened by deposition by the cytoplasm of such strengthening materials as cellulose or lignin, which constitute the basis of woody tissue. The walls of animal cells contain no cellulose as a rule, although there are exceptions.

Cells tend to be spherical but when combined into tissues they are more likely to be cubical or hexagonal, due to the pressure of one cell against another. Sometimes they may be greatly modified in shape, as in the long tubular vessels characteristic of many of the plants, or the nerve cells of many animals, which are character-

ized by many branching processes. In size, cells differ all the way from those which can hardly be seen with the most powerful magnification, to large ones, such as those found in the pith of some shrubs, which can easily be seen with the unaided eye. In some of the larger seaweeds there are even single cells which are several feet in length.

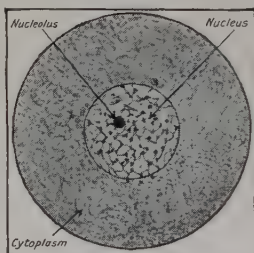


Fig. 4. Structure of a cell

ORGANS AND FUNCTIONS

Some animals and plants are so simple in structure that they consist of but a single cell. Most of these are microscopic in size, although a few of them are larger; a much greater number of living organisms, including all those of any considerable size, are composed of many cells. In these multicellular organisms, the cells are more or less diversified in shape and structure, each type being



Fig. 5. One of the billions of cells in the human body

especially adapted to some special work or function. This specialization, sometimes referred to as "division of labor," is characteristic of all except the most simple types of multicellular life, and the cells set apart for definite functions are usually organized into tissues.

In the higher animals four types of tissues are recognized. The *epithelial* tissues include the outer skin, the lining of the entire digestive system with its secretory glands, the lining of the blood vessels and all other conducting tubes, in fact all surfaces either outside or within the body. In general, they are protective tissues, composed of cells of a simple type which are cemented together to form a continuous surface. The *substantive* tissues include such supporting tissues as tendons or ligaments, and also the adipose tissues which store fat. The *contractile* tissues are those which contract to produce motion in any part, or locomotion of the

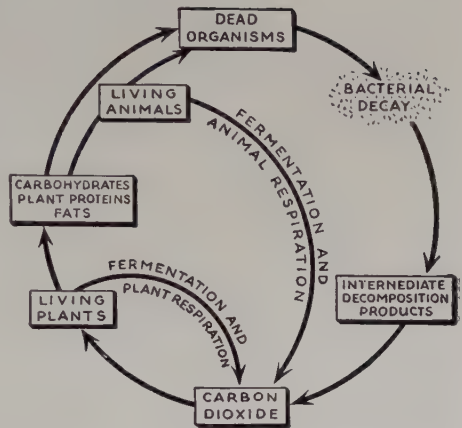


Fig. 7. The cycle of plant and animal life

organism as a whole, the muscles for the most part. The *nervous* tissues serve to receive stimuli and to transmit impulses. Their structure and the means by which their work is carried on will be described in discussing the nervous functions. One or several of these tissues may be combined to

form an organ. Each organ may have its own function or functions to perform, and the entire organism is a highly complex system of such organs co-operating in the whole life process.

Life in any organism is composed of a complex of functions of many sorts, and those which are essential for life are commonly referred to as the *vital* functions. In the process of living, these are all closely correlated, no one function be-

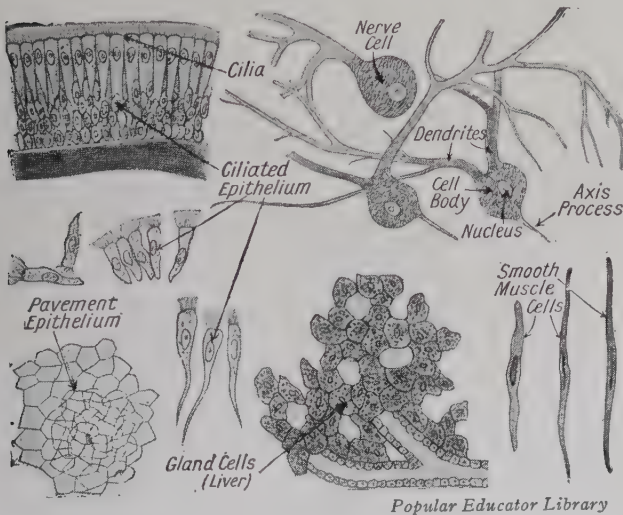


Fig. 6. A great variety of cells are found in the human body

ing carried out independently of the others, but for the purpose of description they can best be considered separately. The most important are as follows.

NUTRITIVE FUNCTIONS

These are concerned with the intake of food, which furnishes both energy and the materials for growth and repair, the preparation and use of this food material, and the elimination of the portions which are not used. The intake of food into the body is *ingestion*. It may be accomplished by special parts such as the mouth and gullet, or in some of the more simple forms of life it may be a simple matter of direct absorption into the protoplasm by engulfment, or, in the case of liquids, by the diffusion of a solution through a membrane, a process known as *osmosis*.

The food material must next be made available for absorption by the protoplasm of the body cell or cells. This process constitutes *digestion* and consists of treatment of the food substance with digestive fluids called *enzymes*. The nature and action of these substances is not entirely understood, but they act chemically upon the food to render the insoluble portions soluble and to so change the other portions that they are available for absorption. Digestion may be confined to certain parts of the body where there are tissues specialized for the secretion of digestive juices, or in the less complex organisms it may be accomplished by surrounding the food particles with digestive fluid. In general, carbohydrates such as starches, cellulose, and complex sugars are converted into simple sugars, proteins are broken down into amino acids, fats and oils into fatty acids

and glycerine. These products are available for absorption into the protoplasm of the tissue cells, a process which is known as *assimilation*. After the available material is removed from the food particles, the remaining waste must be eliminated from the body. This constitutes *egestion*. The term *excretion* is applied to the elimination of waste products resulting from other activities of the body. As in the case of ingestion, egestion may be a simple matter of direct ejection from the protoplasm, or it may be accomplished by parts especially adapted for the purpose.

In general, the nutritive functions are performed by special tissues which line the digestive tract or alimentary canal. In our own bodies the parts of this canal are the *mouth*, in which the food is ground up and moistened and carbohydrate digestion begun; the *gullet*, which passes the material on by a process of muscular contraction known as *peristalsis*; the stomach, an expanded portion of the canal in which the digestion of the proteins is commenced; the *intestines*, where the digestion of the carbohydrates and proteins is completed, where the fats are digested, and the digested food is absorbed by the blood stream; and finally the *rectum*, which by muscular contraction forces the solid waste out through the *anus*.

RESPIRATORY FUNCTIONS

The energy combined in food material can be released only by a process of oxidation. This process goes on in the individual cells of any organism. It is initiated and carried on by other enzymes called *oxidases*. It is essentially a chemical process of combustion taking place so slowly that the energy is released very gradually. It

consists of a combination of oxygen with the various elements composing food material. As a result of this chemical action, there are formed carbon dioxide, water, which is a combination of oxygen and hydrogen, and other decomposition products. The energy released is used in various ways, sometimes in building up new protoplasm to replace the tissues which are constantly wearing out, in other cases to form new cells (growth), to supply muscular energy, to furnish nervous energy, and in general to supply the whole motivation for life.

The chemical exchange which goes on in any living organism is called *metabolism*. The synthetic processes which build up the more complex chemical substances, such as protoplasm, are included in *anabolism*, while the analytic or breaking-down processes, such as oxidation, are described as *catabolic* and compose the activities which constitute *catabolism*.

In order that these processes may continue, oxygen must be taken into the body and also the waste products resulting from respiration must be eliminated. In the animals of simple structure, this exchange takes place by diffusion through the cell walls, but in the forms in which the body is enclosed in a more or less impervious tegument, or skin, it is the function of especially adapted structures such as gills or lungs, elimination being aided by special excretory organs such as kidneys and sweat glands.

In its common use the term *respiration* is applied to the inhalation of air and the exhalation of waste gases, a process which is often spoken of as "breathing." In its physiological use, it is usually limited to apply to the oxidation processes going on in the tissue cells.



U.S. Public Health Service by Rothstein

Fig. 8. This metabolism chamber at a U.S. Public Health Service hospital contains a bed, radio, reading material, and adequate foods and liquids for a patient's 24-hour stay. Fresh air is pumped into the chamber in measured amounts, and the used air is carefully measured, as are all excretions of the patient, including even his perspiration

CIRCULATORY FUNCTIONS

In any organism the food products for assimilation and the oxygen for respiration must be delivered to the tissues where these functions operate. This may be accomplished by diffusion, but in all the more complex organisms it requires a special transportation system. In plants this is accomplished by a conducting system of cells especially adapted for the purpose.

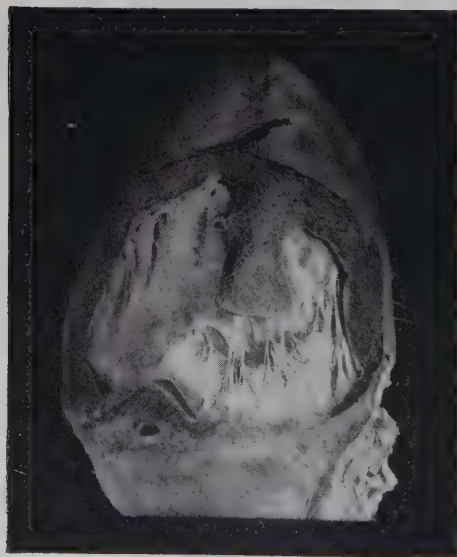
In the animals of more complicated structure it is carried out by the circulatory system of blood vessels. Our

own blood is composed of a fluid portion called the *plasma*; of red corpuscles, which are cells bearing a red pigment known as *hemoglobin*; and white corpuscles, which are unpigmented cells without definite walls and hence varying in shape. The food material is transported by the plasma, and the oxygen is carried in the red corpuscles by the hemoglobin, which has a chemical affinity for that gas. The white corpuscles are not concerned in transportation but serve other functions related to keeping the blood in a healthy condition. The blood is pumped to all parts of the body by the heart, which has muscles especially adapted for the purpose. It is carried from the heart to the body system through vessels called *arteries* and passes thence into the *capillaries*, which are tubes of small caliber distributed throughout the tissues of the body in such a way that

exchange between their contents and the protoplasm of the cells can easily take place. These capillaries in turn lead into the *veins* which conduct the blood back to the heart. As the blood stream passes through the pulmonary or lung capillaries, it picks up its supply of oxygen; as it passes through the capillaries of the intestinal wall it secures its load of food; and as it passes through the capillaries of the system, it delivers these substances to the tissue cells. Here it collects the waste products resulting from respiration and delivers them to the gills, the lungs, or other organs, such as the kidneys, by means of which they are eliminated.

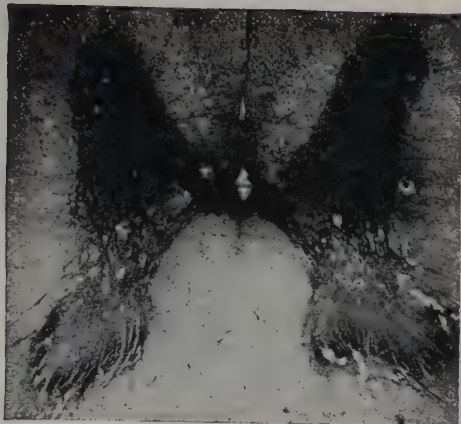
NERVOUS FUNCTIONS

These are concerned with reception of stimuli from the environment and response to these stimuli. They are based upon one of the characteristic properties of protoplasm, namely, *irritability*, the capacity to react to any chemical or mechanical force. In any simple one-celled organism, the action is direct, but in almost all multicellular animals the energy coming from the environment is detected through terminals known as *receptors*, which are composed of nerve cells, highly specialized for energy reception. Examples of such receptors are the *visual* organs or eyes, the *auditory* organs or ears, the *olfactory* organs or nose, the *gustatory* organs, such as the taste buds on the tongue, and the end organs of touch, which are generally distributed over the whole body. These *receptors* with their connections leading to the nervous centers compose the mechanism of the five senses. Receptors also include such light-sensitive areas as are found on some invertebrates in place of eyes,



American Museum of Natural History

Fig. 9. The right ventricle of the human heart, with a section cut away to show the papillary muscles



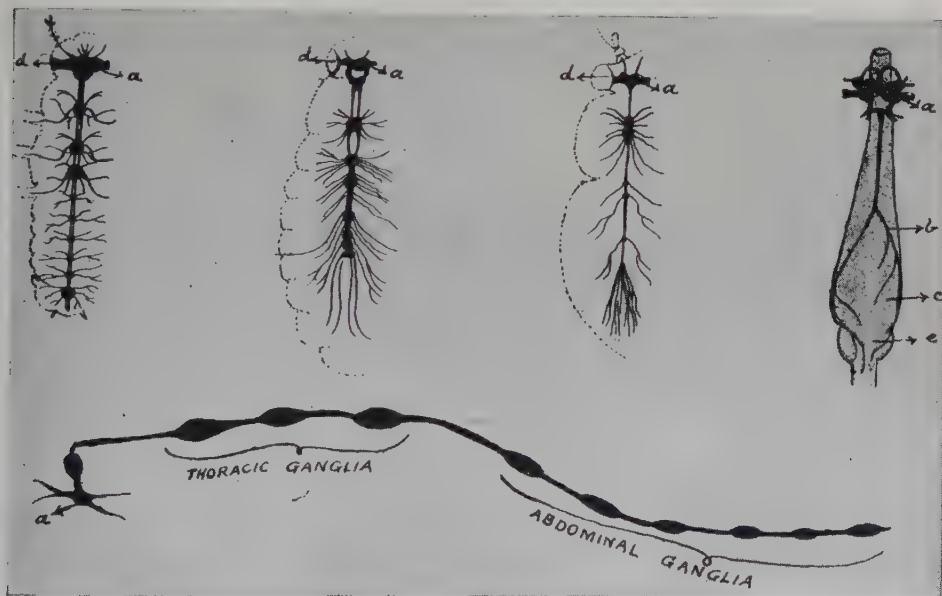
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Fig. 10. This gray substance, which controls countless bodily functions, is embedded in the nerve fibers of the spinal cord in the form of a butterfly

and, in the case of many of the vertebrates, the so-called 'internal senses' such as hunger, thirst, pain, etc.

The stimuli are transmitted from the receptors to *effectors* by means of which body activity is accomplished. Examples are muscles which cause motion, or gland cells which effect secretion. In many cases the transmission is not direct from receptor to effector but instead the receptor passes the stimulus to an *adjustor* which in turn transmits it to one or to several effectors.

The nerve cells which compose these regions are known as *neurons*. A neuron consists of a nucleated cell body which gives rise to two types of processes, *dendrites* and *axons*. The dendrite is much branched near the cell body and serves to receive stimuli, the axon is unbranched, except for occasional collaterals, and transmits the outgoing stimuli. Dendrites are always short and may even be lacking, but axons may extend outward to a



D. Appleton-Century Company

Fig. 11. The nervous system of the Insecta. At top from left to right are *Formica*, *Dytiscus*, *Diptera*, and *Orthoptera* (brain and visceral nerves). *Orthoptera* is also below. a = brain, b = visceral nerves, c = crop, d = eye, and g = gizzard

distance of several feet. For example, some cell centers in the spinal cord are connected with muscles in the distal parts of limbs by single axons.

The neurons are usually grouped into masses of nervous tissue called *ganglia* and their processes are united into cablelike structures called *nerves*. The fibers which make up the nerves are either *sensory* or *motor*. The former carry impulses from the receptor to the nerve center. The latter serve to distribute impulses from the nerve centers to the effectors. Nerves which are composed of sensory fibers only are known as *sensory nerves* while those formed of motor fibers alone are termed *motor nerves*. More commonly nerves are composed of fibers of both types and are referred to as *mixed nerves*.

In our own bodies, as in all vertebrates, the nervous system includes the *central nervous system*, the *peripheral nervous system*, and the *autonomic nervous system*. Part of the last mentioned is more frequently referred to as the *sympathetic system*. The central nervous system includes the brain and the spinal cord, which runs the length of the body within the backbone. The peripheral nerves connect the central system with the sense organs, muscles, and other parts of the body. The autonomic consists of two chains of longitudinally connected ganglia lying next to the backbone and, in addition, various centers and fibers which connect these with the visceral organs, the blood vessels, and also the central nervous system. It serves to regulate the action of such parts as the heart muscles, the digestive glands, the muscles in the walls of the blood vessels and certain other structures such as the erector muscles of the hair. Most of the activi-

ties which it regulates are involuntary although they may be influenced by emotional states. It is likewise true that the autonomic system plays a large part in emotional activity.

In the animal kingdom, as we advance to the more and more complex types, the nervous control becomes centered more and more in the brain, but, even in our own bodies, it is not entirely so. Conscious action is stimulated by impulses generated in the brain, often influenced by impulses transmitted to the brain by the receptors. As indicated above, many of our involuntary actions are controlled by the autonomic system. Many other activities of a more or less involuntary nature are of the sort known as reflexes. An impulse received by a receptor, such as a sensory ending in the skin, is passed through the dendrites of the sensory neuron to its cell body, which lies inside a ganglion just outside the spinal cord. It is then passed on by the axon to the dendrite of a motor neuron, the body of which lies within the spinal cord. The axon of the motor neuron then conveys the impulse to its terminus in the effector, and the response to the stimulus takes place. The nervous mechanism concerned is known as a *reflex arc*. The action described is an example of a simple reflex. In the vertebrates, at least, most all reflexes are more complicated, and are dependent upon the interaction of several reflex arcs. For example, a strong stimulus, such as a pin prick on the finger, which causes the hand to be jerked away from the pin point, will also produce a sense of pain and often a vocal response.

ENDOCRINE GLANDS

Of nearly equal importance to the nervous system in keeping the parts

of the body in harmonious operation are the so-called ductless or endocrine glands. These include the thyroid, composed of two lobes located on either side of the lower part of the larynx; the parathyroids, four minute glands attached to the thyroids; the pituitary body, attached by a stalk to the base of the brain, and lying in a depression in the floor of the skull; and the adrenals which are associated with the kidneys. They are called ductless glands because their secretions do not pass out through ducts, as do the products of most glands, but are absorbed directly into the blood or lymph, and circulated through the body. For this reason these are spoken of as internal secretions although they are more specifically referred to as hormones or "chemical messengers." The thymus, occurring just beneath the thyroid, and the pineal gland, a small body upon the roof of the brain, are also commonly regarded as having endocrinal functions although this is not absolutely established. Also the sex glands, in addition to their reproductive functions, serve as glands of internal secretion, as likewise do special areas in the pancreas, the stomach, and the upper intestine. Even the spleen, the liver, the lymph glands, the kidneys, and the heart have all been suspected of endocrinal functions, although the evidence is as yet inconclusive.

The endocrines are characteristic of all vertebrates. Structurally they are more closely connected with the circulatory system, but in function they are so definitely correlated with body control that they are more logically considered in connection with the nervous functions.

The thyroid is known to have definite control over certain aspects of

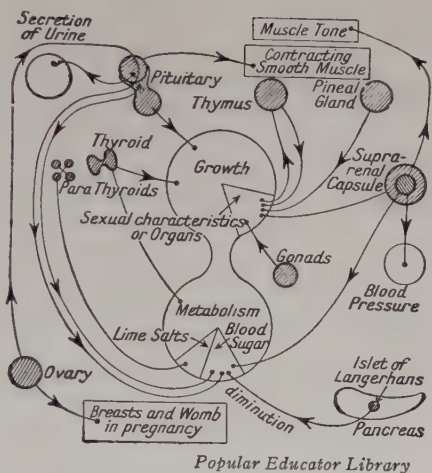


Fig. 12. Diagram showing the action of the endocrine glands

growth and development, apparently by regulating the oxidation rate. Too much thyroid secretion may lead to exophthalmic goiter, characterized by bulging eyes, excitability and thinness, while an insufficiency impedes the processes of the body, lowers the body temperature, and produces other disturbances both physical and mental. Inadequate thyroid development in a young child produces cretinism, characterized by a stunted body and mental weakness, even to imbecility. The condition can be greatly improved and, when taken in time, practically cured by injecting thyroid extract. The parathyroids help to control the calcium content of the blood and thus indirectly affect skeletal growth, blood-clotting and muscular tone. Their removal is followed in a few days by death.

The pituitary is composed of two parts, an anterior lobe which arises embryologically from the roof of the mouth, and a posterior lobe which originates by an infolding of the floor

of the brain. Injections of extracts of the posterior lobe indicate that its secretions act as a stimulant to certain types of muscles, and that it probably exerts control over heart, glandular, and respiratory action. Overactivity of the anterior lobe probably leads to gigantism, insufficiency to dwarfing. There is also some evidence of control over ovulation, and perhaps over the time of sexual maturity.

Adrenalin, the secretion from the adrenal glands, is one of the few hormones which have been actually isolated. It has also been synthesized in the laboratory, and is used widely as a drug. In general it appears to affect the same parts of the body as does the sympathetic nervous system; namely, the heart, blood vessels, involuntary muscles, kidneys, and the viscera. It is possible that the action

of adrenalin is effected through that system. It constricts blood vessels and is therefore very useful to check bleeding in minor surgery. It is used to relieve bronchial spasms in asthma and has other medical uses. In cases of collapse, it is sometimes effective in initiating renewed activity in a heart which has ceased to beat, for it stimulates the sympathetic accelerator muscles. The secretion of the adrenals in the body is not very well understood but there is evidence that some of the effects common to emotional excitement may be brought about by an increased output of adrenalin. The ability of animals to accomplish unusual feats of valor, strength, or endurance when under emotional stress may in part be due to sudden secretion from the adrenal glands stimulated by the stress.



Science Service

Fig. 13. This drawing (by Marguerite Burgess) illustrates the awakening of patients under insulin-shock treatment of dementia praecox. Actual photographs are not allowed in order to protect the identities of the patients

It is definitely proven that in vertebrates the internal secretions from the sex glands control the development of most of those structures which distinguish the sexes, such as the beard of man, the wattles, comb, and plumage of the cock, etc. These are called secondary sex characters and experiments with many animals have demonstrated that they can be suppressed by castration or called forth by transplantation of the sex glands from one sex into another, or even by injection of their extracts.

In addition to secreting certain important digestive fluids through its duct, the pancreas also secretes *insulin* into the blood stream. This serves, probably in co-operation with the secretion from the adrenals, to control the metabolism of sugar in the body. An insufficiency of insulin leads to the condition known as diabetes. The insulin now so widely used in treatment of diabetes is an extract prepared from the pancreas of healthy animals.

The function of the secretion from the thymus is a matter of debate, but removal of that gland appears to interfere with growth, particularly with skeletal development. The pineal appears to be most active during childhood and its degeneration has been found to be associated with precocious sexual maturity.

Most of our knowledge of the endocrinal functions is comparatively recent and, in the burst of enthusiasm which so often accompanies new discoveries, the tendency has been to overemphasize their importance in certain respects. This has been true of certain of the less respectable members of the medical profession, and of some of the so-called popular writers on medicine and biology. Al-

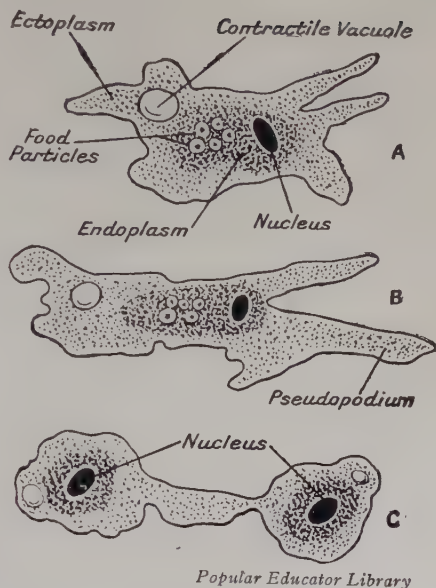


Fig. 14. The digestive and reproductive functions of an amoeba

though it is possible to infer a great deal about the functions of the endocrines by using their extracts, by removing them from the bodies of live animals, and by studying the effects of glandular diseases, there is still much to be learned, and much more which is not yet clearly understood. Especially is this true with respect to the interactions of the endocrines upon one another within the complicated structure of the living body.

REPRODUCTIVE FUNCTIONS

Although one of the characteristic properties of protoplasm is its ability to reproduce itself, it also wears out or breaks down with use, and in any organism the balance between these two activities is such that there is a definite limit to growth in size, and to duration of life. Therefore, if life is to endure, provision must be made for the production of new individuals.

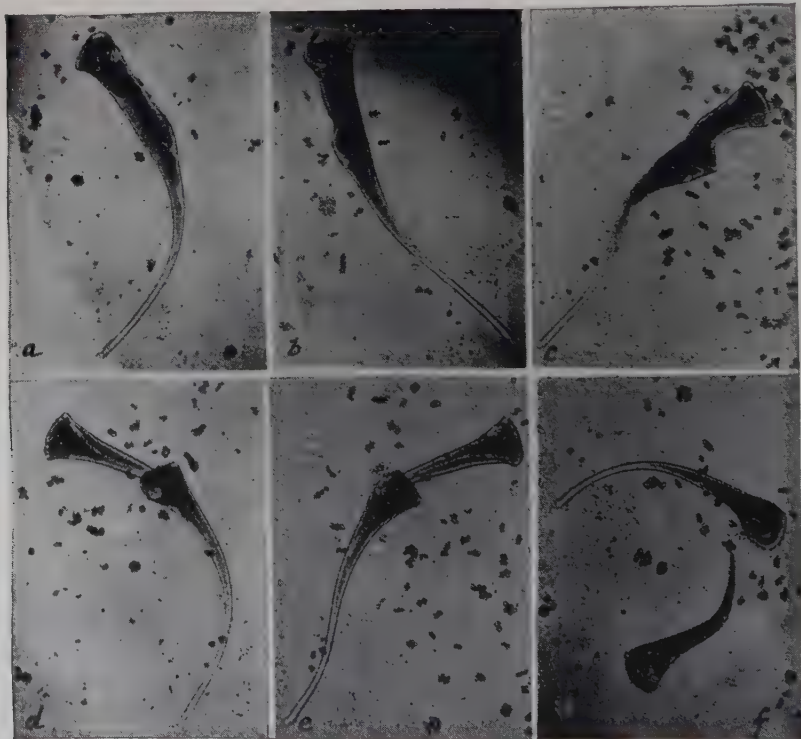
Three methods by which this is accomplished are recognized. They are:

Asexual division, in which the whole body divides into two more or less similar parts. If the two parts are approximately of the same size, the process is termed "fission," but if it consists of the separation of a smaller potential organism or bud from the parent body, it is known as *budding*. This method of reproduction is typical of unicellular organisms and common to many of the simple multicellular forms. Since the individuals resulting from the process have the same protoplasmic constitution as the single parent, they show little variation.

Conjugation is the union of two similar unicellular organisms. This

may be accomplished by complete and permanent fusion, or it may be simply a temporary union of two individuals which exchange protoplasmic materials and then separate.

It should be observed that in one sense this is not a process of reproduction inasmuch as it does not result in an increase in the number of individuals. In fact, in the case of fusion, two or even a greater number of individuals may unite so that the total population is decreased. It is considered as a reproductive process however, for in many forms it appears to be a necessary preparation for continued asexual division. Furthermore, it is viewed as the forerunner of sexual reproduction. Since the conjugat-



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Fig. 15. A single-celled animal becomes two. A stentor, a protozoan with a trumpet-shaped body, gradually divides into two independent animals

ing individuals may originate from different strains (parental stocks), there is some opportunity for the formation of new combinations of characters, and consequently the chances for variation are increased. However, the chief value of the process appears to lie in renewing the capacity for reproduction and possibly in increasing vigor since by constant division the organism may be weakened.

Sexual reproduction, the reproductive process in which two specialized reproductive cells called *gametes* fuse to form a *zygote* which will develop into a new individual. This act is spoken of as "fertilization." The gametes may be of the same size or of different size. If the difference in size is considerable, the larger gamete is called the *egg* and the smaller the *sperm cell* or *spermatozoon*. The egg is commonly rich in stored food and has no means of locomotion, while the sperm is very small and motile. The contributor of the sperm cell is called the *male* and the parent of the egg is called the *female*. The egg and sperm are frequently referred to as the "germ cells." In some animals both gametes are borne by the same individual, a condition known as *hermaphroditism*. In plants the two gametes are more commonly on the same individual, in fact in the flowering plants, a flower without both is classed as an "incomplete" flower.

After fertilization the zygote develops its own entity. From the inception of this process until its principal developmental stages are completed, it is known as the *embryo*, and the study of these early stages is embryology. Usually fertilization is necessary to initiate this development, but in some cases, in both animals and plants, the embryo develops from an

unfertilized egg. This phenomenon is called *parthenogenesis*.

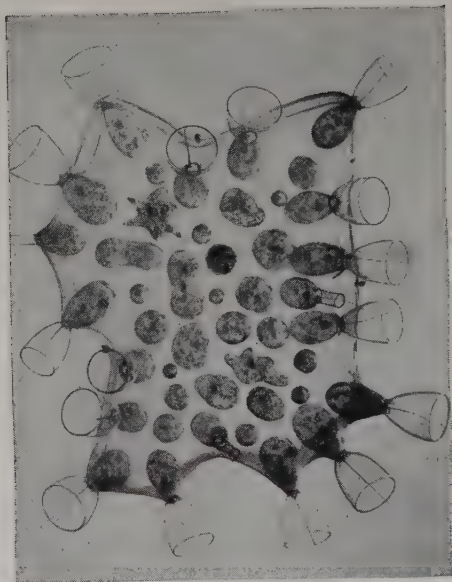
Sexual reproduction is a true reproductive process, since one, or even more, new entities are created. In the case of bisexual reproduction, with two entities participating, the chances for variation are increased in proportion to the germinal difference between the parents.

LOCOMOTOR FUNCTIONS

Locomotion is the act by which an organism moves from one place to another. In unicellular organisms this may take place by a change in shape, by which the protoplasm simply flows from one locality to another, by the propulsion of a whiplashlike process, called a *flagellum*, or by the vibration of small hairlike appendages called *cilia*. In the multicellular forms of animals it is usually accomplished by specialized locomotor muscles which bring about the movement of appendages such as tentacles, legs, arms, or wings. Some of the multicellular animals and most of the multicellular plants have no locomotive structures and are *sedentary*. This is true of some of the unicellular forms of both animals and plants, although the majority of these types are motile.

CLASSIFICATION

All living things are divided into two major groups, the animal kingdom and the plant or vegetable kingdom. Each of these groups is then divided into several *phyla*, each phylum into its *classes*, the classes in turn are composed of *orders*, the orders of *families*, the families of *genera*, and each genus is made up of one or more *species*. For example, the lion is known to the zoologist as *Felis leo*,



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Fig. 16. A glass model of a protozoan (*Proterospongia Haeckel*), showing clearly the cup-like flagella which propel it

and all lions, regardless of individual differences, are classified in this species. The leopard is sufficiently different in his characteristics to be classified in a different species, but he is so much like the lion in so many respects that he is placed in the same genus and is known as *Felis pardus*. The cheetah, on the other hand, is sufficiently different to be classified in another genus, yet it is so like the other cats that it is placed in the cat family, or *Felidae*. The house cat, *Felis domestica*, belongs to the same family, but man's friend, the dog, differs enough from the cats to be classified in a different family, the *Canidae*, or dog family. Since the animals in both of these families are carnivorous, they are included with other families of carnivores in the order *Carnivora*. Likewise, the *Car-*

nivora are grouped with all of the other orders in which the young are born alive, and suckled from mammary glands, into the class *Mammalia*, or mammals. The mammals, being vertebrates, are classed with such other backboneed animals as fishes, reptiles, and birds, in the subphylum *Vertebrata*, the members of which are classified with other animals with similar characteristics into the phylum *Chordata*.

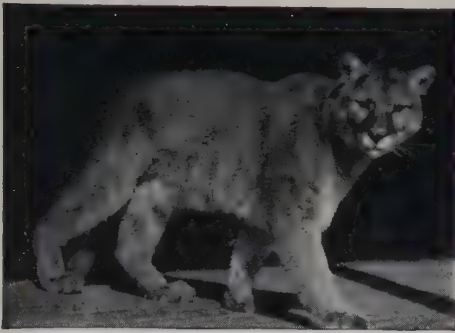
Thirteen phyla are usually recognized as constituting the animal kingdom, but classification systems by different authorities will be found to differ as to the size, arrangement, and further subdivision of the groups. This lack of agreement results from differences of opinion as to just how extensive certain groups should be, exactly how wide a diversity of individual differences should be allowed in a species, or precisely which species should be included within any one genus. The aim of modern systematic practice is to arrive at a natural system of classification, that is, one which is based upon relationship. Since the marks of such relationship are frequently obscure, there are uncertainties which give rise to divergence of opinion among systematic workers.

The practice of using Greek or Latin scientific names quite naturally began with the Greeks and the Romans, who did the earliest work in systematic biology. In their time these were the names in common use. With the renewal of interest in the study of plants and animals in the centuries following the Renaissance, the practice was continued because Latin was the language used in all scientific literature at that time. There was much confusion in the application of these

names, however, until the middle of the eighteenth century, when Linnaeus, the great Swedish botanist, introduced the system of binomial nomenclature by which each kind of animal and plant is designated by two names, one for the genus and one for the species.

Since that time this usage has become universal. The Latin names have been retained, in part through custom, but more especially because they have proved to be so useful in avoid-

ing linguistic confusion. Any one animal or plant may have many common names in the languages of different nations, but its Latin name is the same in all countries. This usage also avoids the confusion which results from the application of different common names to the same plant, or the same name to different plants, in various regions of any one country. In this practice the names are usually Greek or Latin, but the endings indicating case or gender are Latin.



N.Y. Zoological Society

Fig. 17. The puma (left) and the lynx, or bobcat, are both members of the cat family. Hence both have the generic name of *Felis*, to which the puma adds *concolor*, and the lynx, *rufus*. Sometimes, however, the lynx is given its own generic name, and then it becomes *Lynx rufus*

CHAPTER 18

THE PLANT WORLD

ALTHOUGH it is the common practice to divide the organic realm into the animal and the vegetable kingdoms, there is in reality no sharp line of distinction between these two groups. Plants, like animals, are living organisms, hence they must carry on the functions necessary for life. They must be able to derive energy from the environment, and they must have the capacity to use this energy for the maintenance of the individual and for the propagation of the group. Both plants and animals are protoplasmic organisms with the protoplasm organized into one or more cells. In the multicellular types of both groups the cells are combined into tissues and organs with definite functions to perform.

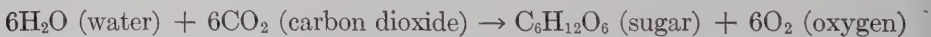
In the more complex forms they have certain characteristic differences in structure, and they differ in their manner of carrying out their functions, but in the simpler types the distinction between them is less evident. In fact, the systematic position of some of the more simple organisms is so much a matter of doubt that they are included in both zoological and botanical classifications. It is as though both groups had their origin from a common stock, and apparently some of the more primitive types have diverged so slightly from the common basic pattern that they have never

consider only those differences in structure and function which are significant in the relation of these forms to their environment.

The most significant of the differences between plants and animals in general is that pertaining to the carrying out of the nutritive functions. Plants and animals alike require food to build up new tissues for growth, to repair waste, and to provide material for the liberation of energy. Both plants and animals require water, inorganic salts, and organic substances like carbohydrates and proteins. Both forms absorb their water and inorganic salts directly, but the animals must have their organic substance supplied in the form of carbohydrate and protein, while some plants have the capacity of synthesizing carbohydrate from inorganic material.

PHOTOSYNTHESIS

This process of carbohydrate manufacture is called photosynthesis. It is restricted to green plants, and under natural conditions it can take place only in sunlight. It consists of the chemical combination of water (hydrogen and oxygen) with carbon dioxide (carbon and oxygen) to form a simple type of plant sugar (carbon, hydrogen, and oxygen). The process can be simply stated by a chemical equation as follows:



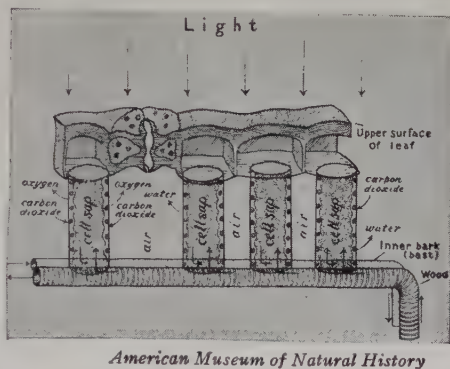
developed to any distinguishing degree the structures which characterize the more complex forms of either line. For our purpose it is necessary to con-

Actually the process is much more complex than this equation implies, with several transitional reactions and certain temporary intermediate prod-

ucts, but the end products are always sugar and oxygen. Sunlight is necessary to furnish the energy required for the chemical reaction, and in the process this radiant energy is converted into chemical energy which is stored up in the sugar manufactured. The oxygen is released as a by-product, most of it diffusing into the atmosphere. The process can operate only in green plants because it is the green pigment, *chlorophyll*, which absorbs the sun's energy. In all of the higher plants, most of this photosynthetic activity takes place in the green leaves, although any part of the plant which is green may carry on the operation. The chlorophyll is not distributed throughout the protoplasm of the plant cells, but is contained within the plastids, which in this case are called chloroplastids, or simply chloroplasts. In Fig. 2 showing the section of a leaf, as seen through a microscope, the chloroplasts can be seen arranged around the periphery of each of the cells which contain them. This arrangement places them in a favorable position to absorb the light which penetrates the leaf tissues. The supply of water is furnished by the veins of the leaf and the carbon dioxide gas enters through the small pores, called stomates, which perforate the epidermis of the leaf. More commonly these stomates are restricted to the lower surface of a leaf.

It has been estimated that for many plants the average rate of sugar manufacture is about one gram per hour for each square yard of leaf surface. This would amount to about a level tablespoonful in a single day. At first thought this seems like an insignificant amount, yet when one takes into account the millions of square yards

of leaf surface represented by our forests, our grassy plains, and our cultivated fields, the total amount of sugar manufactured adds up to figures which are beyond our comprehension. The commercial sugar production for the world is in the neighborhood of



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Fig. 1. This diagrammatic illustration shows what happens when light strikes the surface of a leaf

thirty million tons per year, yet this represents merely the product of two crops, sugar cane and sugar beets. Add to this the products of all of our carbohydrate crops, such as the many cereals and potatoes, then consider that our crop plants represent but a minor part of all of the green plants on the earth, and one begins to get some conception of the tremendous amount of sugar produced by photosynthesis. The importance of the process can hardly be overemphasized, for it is the only means by which the energy of sunlight can be converted into chemical energy available in the shape of food for either animals or plants. Man, with all his inventive ingenuity, has neither been able to duplicate the process, nor to find a substitute for it. If it were not for the chlorophyll in plant cells, life as we know it would not be possible.

The green plants may use the simple sugar resulting from photosynthesis as a source of energy and tissue building, or they may convert it into storage forms such as more complex sugars, starch, oil, or cellulose. The latter process may go on in the cells in which the simple sugar is formed, or this sugar may be translocated to specialized storage tissues in other parts of the plant where it becomes changed into storage forms. In either case these storage products must be once more converted into a simple sugar before they are available for use. This conversion constitutes digestion; in plants it is accomplished by means of enzymes, just as it is in animals.

The available carbohydrate is also used by the plants as the basis of proteid foods, and in such combinations it may be built up into proto-

sary elements are absorbed in the form of soluble nitrates, sulphates, and phosphates of potassium, calcium, and magnesium. Other elements, particularly iron, are required but their role in the living process is not entirely understood.

THE CARBON CYCLE

The radiant energy converted by photosynthesis into potential energy in the form of food, becomes available as heat energy if the plant products are burned with a sufficient supply of oxygen. This process, which we call combustion, is chemically a process of oxidation in which the oxygen combines with the carbon of the carbohydrate to form carbon dioxide, and with the carbohydrate hydrogen to form water. If the green plants, or their products, are eaten by animals, the carbohydrates which they contain may be used directly in animal respiration, or they may be converted into animal carbohydrates; likewise vegetable oils or fats may be converted into animal fats, or plant proteins may be changed into animal proteins. After being made available by digestion within the animal, any of these substances may be used in animal metabolism. If used in respiration, the process is nothing more than one of slow combustion, which takes place in the presence of the oxidase enzymes. Like combustion, this is an oxidation process and—again as in combustion—the products are carbon dioxide and water. These substances, leaving the animal's body as waste products, become available for use by the green plants as the raw materials for photosynthesis. Likewise, the oxygen given off as a by-product of photosynthesis becomes available for the oxidation of respiration by animals.

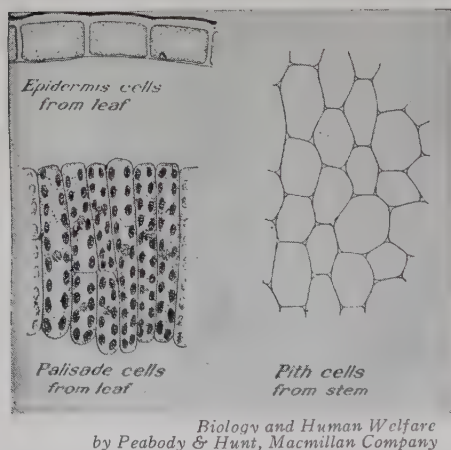


Fig. 2. Three types of cells of plant tissues

plasm. This requires the addition of the chemical elements nitrogen, sulphur, and phosphorus, together with such mineral elements as potassium, calcium, and magnesium. These neces-

This process of chemical exchange between the animals and the plants is commonly referred to as the *carbon cycle*, and the balance between the products is such that the amounts of oxygen and carbon dioxide in the atmosphere remain practically constant. In addition to the green plants there are others (the fungi and other parasites described below) which do not possess chlorophyll. These are also dependent upon the green plants in much the same manner as the animals, and they occupy a similar position in the carbon cycle.

This carbon cycle is also completed within the tissues of the green plant itself. When the sun is shining on a green plant some of the oxygen liberated by photosynthesis is immediately utilized by respiration within the plant tissues. Likewise, the carbon dioxide eliminated in respiration may be used up in photosynthesis. However, under such conditions the ratio of respiration to photosynthesis is about one to ten, therefore more oxygen is formed than is needed and this gas is liberated. During the night, when there is no photosynthesis to consume carbon dioxide, this gas is liberated. Throughout the course of a whole day (24 hours) the ratio between respiration and photosynthesis is about one to five so that the total amount of oxygen liberated exceeds the amount of carbon dioxide consumed.

In unicellular plants, and in the multicellular forms of simple structure, the nutritive process differs from that in similar types of animals to the extent that food substances, both inorganic and organic, cannot be ingested in the solid state but must be absorbed in solution. This is due to the fact, previously emphasized, that

plant cells have walls of cellulose. In these plants nutritive material is taken in through almost any part of the surface. In the more complex forms of plants, in place of a mouth for ingestion, as in animals, there is some special region adapted for absorption. This is usually part of the root system. In the roots this function is usually performed by structures called *root hairs*, growing just back of the root tip. They are very abundant within a restricted region and each of them is nothing more than a tubular proliferation of a surface cell. These hairs penetrating between the soil particles absorb the soil moisture and the salts which it holds in solution. The water is absorbed by a process known to the physicist as *osmosis*. Whenever two solutions of different concentration are separated by a membrane which is permeable to water, the less concentrated solution gives up water to the more concentrated. Actually in the root hair the water moves in between the very fine particles of pectin and cellulose which compose its wall by another process called *imbibition*, but, having penetrated the cell wall, it then passes by osmosis through the protoplasmic layer which lines the inside of the root-hair cell. This takes place because the solution inside the root hair contains a higher concentration of solutes (mostly sugar) than does the soil solution (mostly soil salts) outside.

Passing into the root hair, and thence into the root cell proper, this additional water sets up a hydrostatic pressure on the cell wall. It also lowers the concentration of the cell solution. This upsets the osmotic relation between this cell and the adjacent cell in the inner tissue of the root, and this change in relative osmotic pres-

sure, together with the increase of hydrostatic pressure, causes the water to move on to deeper and deeper tissues in the root. The soluble salts in the soil water are not swept along in this inward flow of water. They move entirely by diffusion, a process in which any solute will move from regions of higher to regions of lower concentration. The passage of any particular salt is dependent on the concentration of that one salt alone. That is, even though the total concentration of salts within the root hair might be greater than the total concentration of soil solutes outside, some one salt, such as potassium nitrate, would diffuse into the root hair if there were less potassium nitrate inside than without. At the same time some other salt might be passing from the root hair to the soil solution, if it happened to be present in greater quantity inside. This whole process of absorption of solutes is further complicated by the fact that the protoplasmic lining of the root hair may be permeable to some salts and not to others, or its permeability may change under different conditions so that a certain salt may pass through it at one time and not at another. It is this selective permeability of the protoplasmic lining of the root hair which prevents the cell from losing its sugar by diffusion.

In aquatic plants root hairs are often lacking, and sometimes the whole root system is greatly reduced, or even absent. In such plants absorption takes place through most any part of the immersed surface.

TRANSPORTATION

The water and the salts absorbed into the roots are transported to the other parts of the plant through a

complex system of water-conducting tissues which extend from the region of the root hairs, near the tips of the main root or each of its branches, through the length of the root and the stem into the leaves, where they constitute the veins. The structure of the cells which compose this conducting system varies in different kinds of plants, but they are all well adapted to their work, with their walls either abundantly pitted for better communication, or with the end walls greatly reduced, or lacking, so that continuous tubes extend for some distances in the tissues of the stem. In all of them the protoplasmic contents disappear soon after the cells are formed, thus the water-conducting tissues are largely dead cells.

In a tree the vessels carrying the water and inorganic salts constitute a large part of the woody tissue, while the transportation of elaborated foods is carried on by vascular tissue in the inner bark. In herbaceous plants the conducting tissues are similarly located. In the plants there is no pump like the animal heart to keep these fluids in circulation. The movement of water and solutes from the roots to the leaves is spoken of as the *ascent of sap*. The physics of the process is not understood and its cause is a matter of controversy, although it is clear that it is at least assisted by evaporation of water from the leaves (*transpiration*). Considering that some of our highest trees, like the Sequoias of California, are sometimes over 300 feet high, it is evident that a considerable force is necessary. The passage of elaborated foods through the bark is probably largely a matter of diffusion and osmosis.

Just how necessary the process of transpiration is for the life of the

plant is a question. As indicated above, it may play an important role in the process of water conduction. It has also been looked upon as of some value in preventing plant temperatures from going too high. In later years the botanist has come to realize that the latter role is of very ques-

REPRODUCTIVE FUNCTIONS

In their reproductive processes plants do not differ essentially from animals. Types of simple organization reproduce by asexual division. Other more complex organisms show the various stages of transition toward the development of true bisexual re-

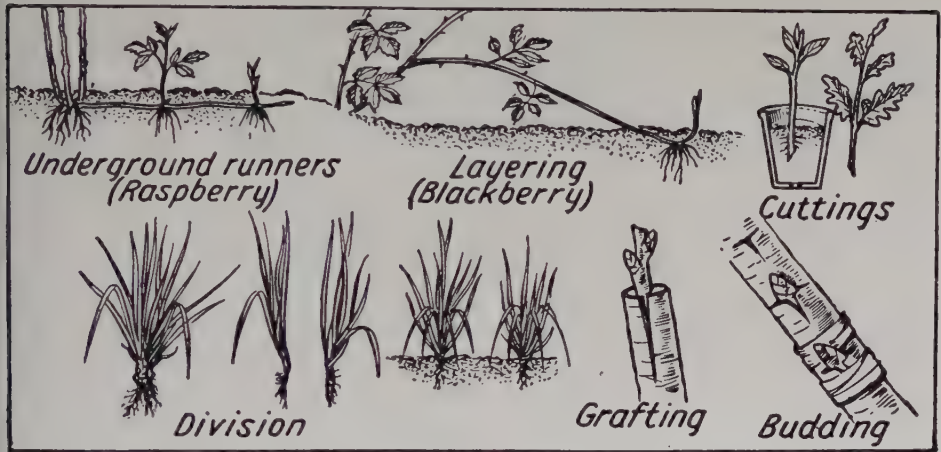
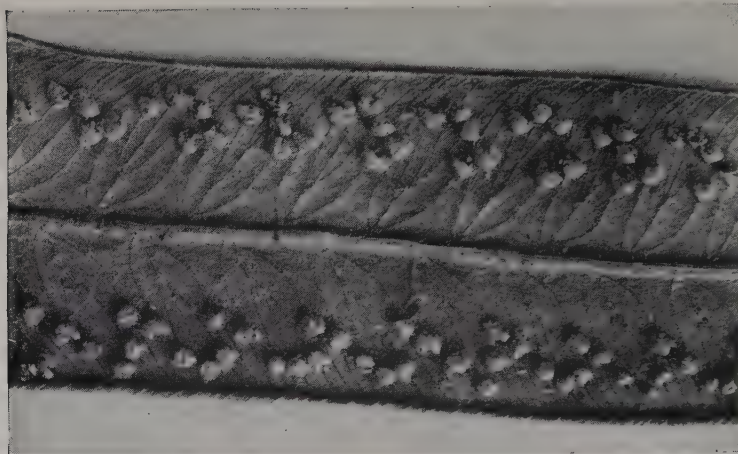


Fig. 3. Some of the ways—other than by seeding—in which plants can grow and multiply

tionable value, and he is far from sure that the process is essential in water conduction. The modern view is more inclined to look upon transpiration as more of a necessary evil; the surface tissues of a plant must be porous to allow for the absolutely essential exchange of gases, and a porous surface means that evaporation cannot be avoided. In most plants possessing stomates, there is an ingenious mechanism by means of which the size of the opening may be regulated to allow for some degree of control of the rate of evaporation, but this mechanism is effective in completely closing the opening only after a leaf has already lost so much water that it begins to wilt.

production, with female gametes (eggs) and male gametes (sperms).

In asexual reproduction, unicellular plants may divide by a process of simple fission like that previously described for animals. In the case of multicellular forms in both animals and plants, this division of the individual cells constitutes growth. Also in the multicellular plants of more simple organization the whole plant body may divide into two individuals by a process of fission, or one individual may form new organisms by budding. This is spoken of as *vegetative reproduction* and in the plant group it occurs as a reproductive process even in the most complex forms. Instances of it are seen in the



Smithsonian Institution

Fig. 4. The under side of a fern leaf, much enlarged, shows the spores which are an important part of the reproductive process of the ferns

methods of propagating cultivated plants by means of dividing one individual into several, and letting the new parts take root, as in the case of potato tubers, lily bulbs, or strawberry-plant runners. The common practice of "slipping" house plants by cutting off a branch and allowing it to form a new root system is a good example.

Another type of asexual reproduction common to plants is spore formation. A *spore* is a single cell, or small group of cells, which separates from the parent organism and develops into a new individual without union with another cell. It may be formed from the contents of one cell, or the protoplasm of one cell may separate into a number of entities, each of which becomes surrounded with an individual wall to form a spore. The cavity in which spores are borne is called a *sporangium*. As a rule spores possess the power of retaining their vitality under conditions which are prohibitive for ordinary protoplasmic

activity. This faculty is due in part to the formation of a comparatively thick wall which is unusually impervious to the evaporation of moisture from within. In addition, the protoplasm of the spore appears to be denser, and in some little understood fashion it can remain

in a living condition in such a dormant state that the products of metabolic activity can scarcely be detected. The value of this device in carrying organisms through periods of unfavorable growth conditions will be better realized as the life habits of the different groups are described. Similar reproductive structures are found in the animal kingdom, but only among unicellular forms.

NERVOUS FUNCTIONS

Plants possess no system for the transmission of nervous stimuli comparable to the nerve system in animals. Nevertheless, they react to the varied stimuli of the environment. However, in the plant kingdom the reaction can usually be attributed either to pressure changes transmitted from one cell to the next, or to unequal growth in different regions. An instance of the former activity is to be seen in the collapse of all of the leaves of the Sensitive Plant if but one leaf is touched. The downward

growth of a root or upward turning of a shoot in response to gravity or light is due to unequal growth in the tissues on the two opposite sides of these organs. The causal mechanism of this unequal growth is not entirely understood.

Locomotion in the plant kingdom is confined to the unicellular and the most simple of the multicellular forms. Among these, it is brought about in much the same way that it is in the simple animals, by amoeboid movement, by flagella, or by cilia. All of the more complex plants are sedentary.

The study of all the myriad plant functions is a special branch of botanical science known as plant physiology. For purposes of study the plant kingdom is commonly divided into four groups, called divisions, or phyla. These are the thallus plants (Thallophyta), the moss plants (Bryophyta), the fern plants (Pteridophyta), and the seed plants (Spermatophyta), the Latin names enclosed in parentheses being the ones which are used in botanical nomenclature.

THALLUS PLANTS

The thallus plants include the most simple types. They range in structure from unicellular to multicellular forms, often of complex structure, but in no case with a well defined root, stem, or leaf system. They fall naturally into three groups, the *bacteria*, the *algae*, and the *fungi*.

BACTERIA: Bacteria do not possess chlorophyll nor do they have cellulose cell walls, yet they are classified with the plants, principally because they absorb their nutrient material in solution as do plants. In structure they present a type of organ-

ization which is more simple than that of any of the other plant forms. Their protoplasm contains none of the characteristic bodies mentioned in the earlier description of a typical cell, even a nucleus being absent. It is probable that they contain nuclear material but in none of them does an organized nucleus appear.

In size these forms are all microscopic, averaging about one twenty-five thousandth of an inch in diameter. Some are larger than this but many are smaller and there may exist types so small as to be invisible under the microscopes of highest magnifying power. Some forms are even so small as to pass through the pores of the finest filters.

They are found in three shapes and have been classified on the basis of this difference into bacillus (rod-shaped), coccus (spherical), and spirillum (spiral) forms. The coccus forms are non-motile but some species of the other types may move about by means of minute cilia and flagella, either distributed over their surface or localized at one or both ends.

Bacteria may occur singly; in some cases they form long chains, and in other types they habitually form clusters or clumps. The shape of these clusters is frequently distinctive of a certain type and is often used in their classification.

Physiologically the habits of bacteria are very diverse. Possessing no chlorophyll, they cannot synthesize their own organic food supply, consequently most of them are directly or indirectly dependent on organic substances which have been built up by plants. There are a few forms, however, which have a method of life that is unique in the organic realm. These derive their energy from the oxidation

of simple inorganic compounds in which they live—some by oxidizing sulphur compounds and others by a similar oxidation of iron compounds.

The forms which are dependent on organic substances are sometimes parasitic on either plants or animals, and a number of them are the cause of disease in the organisms in which they live. Examples of such diseases are typhoid fever, tuberculosis, small-pox, and anthrax in animals, and fire blight on pear and apple trees. The disease condition in the host is due, in some cases, to the fact that these parasites consume nutrient or interfere with physiological function in other ways. Much more frequently it is brought about by the poisons or *toxins* secreted into the plant or animal system by the bacteria.

The fact that the bacterial organisms can be transferred from one host

to another by contact, or by air, water, or food, means that such diseases are easily communicated from a diseased to a healthy organism. In many cases, in addition to forming toxins, the bacteria stimulate the system to form *antitoxins*. These appear to effect the bacterial wall so as to expose these organisms to destruction by the white blood corpuscles in the mammal, or by other types of *phagocytes* in other animals. Fortunately for the members of the animal kingdom, these antitoxins also induce an immunity from further attack by the same bacterial form. In the fight against these diseases, extended use has been made of this phenomenon of immunity. By injection of controlled amounts of toxins of known activity, or of antitoxins, it has been found possible to establish the same sort of immunity as that induced by the disease itself, but with little or no inconvenience to the subject. A somewhat similar method of inducing immunity is that of *vaccination*. In this process the patient is inoculated with bacterial organisms of the disease, but of a strain of such low virulence that the toxins accomplish little more than to stimulate the formation of antitoxins which set up immunity.

There is no more interesting chapter in the history of science than that which deals with the origin and development of the science of bacteriology and its application to public health and sanitation. It is a comparatively recent chapter, for it was only in 1865 that Louis Pasteur found that certain micro-organisms were the cause of a disease which was epidemic among the silkworms of France to such an extent that it was ruining the silk industry of that country. Bacteria had been recognized for many years



Free-Lance Photographers Guild

Fig. 5. Living rabies tissue is injected into a rabbit's brain. The rabbit will develop a strong resistance to the virus, which, when injected into the blood of an exposed patient, will constitute a powerful rabies anti-toxin

before that, and their role in contagious disease had been suggested, but the idea had never taken root. Pasteur followed up his work on the silkworms with similar investigations of other diseases, and in 1877 both he and Robert Koch, a German medical man, demonstrated that anthrax was due to bacterial infection and could be induced in mice by inoculation. The bacterial nature of other diseases was discovered by Koch, tuberculosis in 1881, and Asiatic cholera in 1883. Through the 1880's Pasteur developed the use of vaccines for some animal diseases, such as hydrophobia in 1885.

Curiously enough, the practice of vaccination for smallpox was introduced nearly one hundred years earlier by an English physician, Edward Jenner. In the eighteenth century it was realized in Europe that a person who had been sick with smallpox was immune from further attack, so it became a custom for people to infect themselves deliberately from a person who had the disease in a mild form, in order to avoid getting it badly. Jenner discovered that the same sort of immunity could be induced in man by inoculation from a cow which was suffering from the somewhat similar cowpox. Today the cow is still used to develop the less virulent strain used for smallpox vaccination, but with many added precautions as to standards of virulence and purity of the vaccines.

The use of vaccines has reduced smallpox from one of the worst scourges known to mankind to one of the less dangerous diseases among civilized people. In fact, where universal vaccination has been adopted, the disease has been practically wiped out. The use of a vaccine of another



University of Missouri

Fig. 6. The nitrogen-fixation nodules on the root of a legume plant

type, in which dead bacteria are injected to cause the body to set up antitoxins, has reduced typhoid fever to such a point that, whereas in army camps it was frequently a more common cause of death than bullets, it is now a rare occurrence. In a like manner, toxin and antitoxin is being used with great success to reduce the mortality from diphtheria among children.

Other forms of bacteria, closely related to disease germs, are those which infect open wounds and cause various kinds of blood poisoning, such as gangrene. Before it was realized that these organisms are commonly present in the air, on the hands, and

even on the surgeon's instruments, major operations were more often fatal, always extremely dangerous, and even minor operations frequently led to fatal infection. Pasteur's work threw a new light on this field, although its application to surgery was begun by a Scotch surgeon, Sir Joseph Lister. It was he who introduced aseptic methods into surgery and devised the use of antiseptics in sterilizing instruments and in dressing wounds. Since his time, the methods have been greatly modified and improved, until now infection during an operation rarely occurs.

All bacteria are not disease-causing organisms. There are some which live in the alimentary tract of animals where they play a necessary role in the working out of the nutritive functions. There are others which live in the roots of plants and aid them in obtaining their supply of nitrogen. These are called "nitrogen-fixing bacteria" because they possess the ability of changing the free nitrogen of the air (which is otherwise not available to plants) into available nitrates. They are found especially in the family of legumes, such as alfalfa, clover, peas, and beans. In agricultural practice extensive use is made of this phenomenon to enrich soils with nitrates by growing leguminous crops in rotation with others which must have nitrates supplied to them. It has also been found possible to grow leguminous crops of this type on soils, which would not originally support them, by inoculating either the seed or the soil with the proper bacteria at the time of planting. Other species of nitrogen-fixing bacteria live independently in the soil.

There are still other forms of bacteria which are used directly by man

in his own economic system. For example, certain forms give a characteristic taste to butter. Some of these characteristic tastes are more pleasant than others. In the older practice it was more or less a matter of luck as to which type flavored any one batch of butter, but in modern dairy practice the taste is kept uniform by inoculation with the desired strain. The familiar taste of certain kinds of cheese, and the characteristic bouquet of wine, is also due in part to bacterial action, although various other micro-organisms play some part in both processes. The fact that different flavors of cheese and wine are characteristic of certain districts is due to certain micro-organisms which are especially abundant in the flora of those districts. Vinegar is made by the action of bacteria which change alcohol into acetic acid, and the "mother of vinegar" consists of these organisms embedded in the slime which they secrete. There are many more bacterial organisms which render valuable service in many other industries.

The greatest role played by the bacteria in the economy of nature is that of decomposing complex organic substances into simpler chemical compounds. This process, which is called "nitrification," takes place in several steps and involves different kinds of bacteria. First the proteins in the organic material in the soil, or on the soil surface, are broken down into amino acids. This is the process which is commonly referred to as decay. Next, by a process called "ammonification," the ammonifying bacteria convert the nitrogen of the amino acids into ammonia. This substance combines at once with other soil chemicals to form ammonium salts,

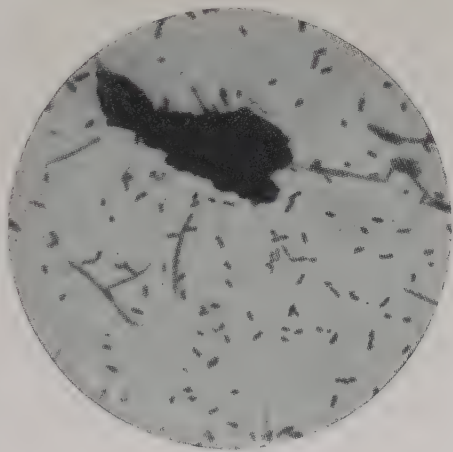
which in two steps are then converted by still other bacteria into soil nitrates which are available to higher plants. The entire process is of the greatest importance, for without the work of these bacteria the surface of the earth would in a short time be so littered with the products of excretion and death, and the available nitrogen would be so tied up in organic tissues, that no life would be possible.

That, in the course of carrying out this important function, these bacteria sometimes attack our own food supplies is not surprising. Our methods of guarding against their attack are numerous. Long before bacteria were recognized, man had discovered that perishable foods could be preserved from decay by drying, by smoking, or by the liberal use of salt, but he did not know why this was so. Since the days of Pasteur we have come to understand that food decay is due to bacteria, and modern methods of food preservation have been developed. It is now realized that drying is effective because bacteria require moisture for life, that strong salt solution kills bacteria by removing water from their protoplasmic contents, and that the smoking of meats or fish forms chemical compounds which prevent bacterial growth. It has also been discovered that, although low temperatures will not kill bacteria, they do prevent their increase, so that foods can be kept almost indefinitely if they are in good condition when first chilled, and are afterwards kept cold.

From our knowledge of the habits of bacteria we have also been able to devise effective methods of canning. These methods are based on the principle of destroying the bacteria in the foods by high temperature and preventing the entrance of any others by

careful sealing. So effectively has this problem of food preservation been solved by refrigeration, and by other methods, that today foodstuffs from all parts of the world are available for our table.

The reproductive methods of bacteria are very simple. Most frequently they multiply by simple fission, the



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Fig. 7. Bacteria are responsible for a great deal of food decay, some of which, like that which creates cheese, is very valuable. Here is a bacterium culture which changes the color of white wafers to red. In medieval days it was believed that the change in color was due to the wrath of God

new cells separating or remaining attached to one another in chains or clusters. In many forms and under favorable conditions this process is repeated every twenty or thirty minutes. A little computation will show that on this basis the descendants of a single individual, if they all remained alive, would number into the millions in the course of twenty-four hours, and in a comparatively short time would crowd all other life from

the earth. Fortunately this rate of growth cannot be maintained, for the food supplies become exhausted and excretions are produced which check their increase. Under ordinary conditions their multiplication may continue at this rapid rate until a point of saturation is reached, which accounts for the quickness with which bacterial diseases will sometimes develop in animals and plants and assume epidemic proportions.

Some bacteria produce spores. This is accomplished by an apparent concentration and rounding off of part of the protoplasmic contents, which then becomes surrounded by a thin wall. This wall thickens to form a protective coating. The remnant of the original organism eventually disappears. When the conditions for growth are favorable, this spore will germinate by a softening of the wall and an assumption of the active condition or, in some cases, by a protrusion of the contents which then form a new wall to become a normal active individual. The point should be made that spore formation of this type is not a reproductive process, since no new individuals are formed. It is simply a device for withstanding unfavorable growing conditions, and it is extremely effective in that function, so much so that vitality can be retained through extreme desiccation, at high temperatures, and even in antiseptic solutions. Boiling destroys bacteria in the active state but does not destroy the spores unless carried on under pressure such that the temperature can be raised above the normal boiling point. Spores of the anthrax bacillus have been found to retain their vitality for as long as fifteen days in a one per cent solution of carbolic acid.

Bacteria have a more universal distribution than any other type of organism. They exist in countless millions in the air, in the water, and in the soil. They are present in and on every living thing, and on the surface of every object exposed to contact with its environment. As causal organisms of disease in man, and in his domestic animals and crops, they are a source of harm. Other forms cause other economic loss. However, the harmful forms are in the minority and the beneficial importance of the work of the bacteria of decay can scarcely be exaggerated.

ALGAE: The forms of algae are commonly classified according to the color of their predominant pigments into blue-green, green, brown, and red algae. They are all characterized by the presence of chlorophyll in their cells, but, in all except the green types, this substance is masked by the pigments of other color. They are primarily aquatic forms.

The blue-green algae are either unicellular or simple filamentous associations of cells. In cell structure they represent a type of organization similar to that of the bacteria, with no organized nucleus, but with the nuclear material distributed through the cell cytoplasm. As indicated by the name, they are bluish-green in color. Since one of the components of this pigment is chlorophyll, they can synthesize their own organic foods. They may rarely give trouble by causing bad taste and odor in water supplies but otherwise are of no economic interest. They are important from the evolutionary view because of their extreme simplicity of structure and also because of the fact that some of them can thrive under

temperatures close to the boiling point. In most cases, the colored deposits found around hot springs owe their color to blue-green algae which grow in abundance in the waters flowing from these springs. They represent a type of life which might have thrived under conditions which were much more severe than those common to the earth's surface today. With a few exceptions, they inhabit fresh waters.

The green algae are in many cases unicellular, and frequently such forms are motile, possessing cilia or flagella by means of which they move about very rapidly. Certain groups display a tendency toward colony formation. Other types are truly multicellular, forming either filamentous or plate-



Science Service.

Fig. 9. *Vaucheria*, one of the green algae forms dark-green floating masses in stagnant water, and felt-like coverings on wet soil. The male cells are produced in the little dark knobs seen very plainly at various points in the above picture



Science Service

Fig. 8. *Gloeotrichia*, one of the blue-green algae, common in stagnant water and on damp soil. Blue-green algae are among the least developed of plants. Their cells have no definitely organized nuclei

shaped bodies. In cell structure they all possess well organized nuclei and chloroplasts.

Like the blue-green algae, these forms are of no real economic importance. They, too, are largely fresh water types, although a few are common in the ocean, such as *Ulva* (the sea lettuce) and some of the most common forms found on the sandy bottoms of shallow tropical seas. Most of these tropical forms secrete lime and play as important a role in building coral reefs as do the coral organisms themselves. The fresh-water types are mostly microscopic in size but some of them form aggregates which are easily visible to the unaided eye. Examples are the filamentous

types which form green scum on the surface of ponds, and green mats on stream bottoms or on damp soil. Certain unicellular types grow so abundantly on damp wood and tree trunks as to cause a green color, and somewhat similar forms frequently become so numerous in small bodies of water as to color it green, a phenomenon known as "water bloom."

The brown algae are practically restricted to a marine habitat. The most common are the rockweeds, which grow so abundantly on the rocky coasts of the colder seas, and the kelps, which inhabit deeper waters but are often found washed up on the more northern beaches. Another well-known form is *Sargassum* (gulfweed), certain species of which are always found floating unattached. Collections of this material brought together in great ocean eddies and covering many square miles of ocean surface, have given the name to the Sargasso Sea.

These particular forms and, in fact, most of the brown algae, are of rather complex tissue structure and grew to a considerable size. Some of the large kelps of the Pacific and the South Atlantic are by actual measurement over 100 feet long. In cell structure they are like the green algae except that the plastids contain a brown, as well as a green, pigment. They are considerably more complex in structure than the greens, with much more definite tissue formation. The brown algae are chemically rich in iodine, potash, and soda, and before the discovery of Chili saltpeter, on some seacoasts quite an industry had been built up for the extraction of these substances.

A curious one-celled form often classified with the brown algae is the diatom. In these, each unicellular or-

ganism surrounds itself with a veritable glass house, a shell of silica. Although microscopic in size, they occur in such abundance, especially in ocean waters, that as they die their empty shells settle to the bottom to form deposits of great thickness. It is from ancient deposits of this sort, which have later been elevated above sea level, that diatomaceous earth is obtained. Because of the extreme fineness of its individual particles, this material forms one of the best polishing powders known to man. It is the basis of most silver polishes and many scouring soaps. The best firebricks are also composed of this material, and it is one of the most common absorbents for nitroglycerin in making dynamite sticks.

The red algae inhabit deeper waters than the brown and are more characteristic of the warmer seas. In organization they are about as complex as the brown algae but do not run to such large sizes. They also are rich in iodine, but as yet no method has been found for extracting it cheaply enough to make it commercially profitable. They are used very largely by oriental people as a source of food and form the basis of a great many Chinese and Japanese dishes, like the well known bird's-nest soup. The Chinese and Japanese even cultivate certain forms which are most commonly used as foods. On our own seacoasts some forms are eaten, namely, dulce and Irish moss. The former is eaten raw after drying, but the Irish moss is used as the basis for blanc mange. It will be found in powdered form on the grocer's shelves under the trade name of "Sea moss farina." A very important use of certain forms of red algae is their manufacture into agar-agar, which is used so widely in the

bacteriological laboratory as a culture medium for growing bacteria under controlled conditions. This industry has its center in Japan, although it is now being developed on the California coast.

In both the red and the brown algae the characteristic pigments occur in addition to chlorophyll, and the pigments of the algae in general are closely correlated to their bathymetric or depth distribution. The

longer wave length which is all-important, but as light penetrates the water of the ocean these longer red and yellow light waves penetrate only a short distance, so that the greater depths receive little except blue light. Because of their fluorescent properties, these pigments have the capacity to convert this blue light to red. Thus the associated chlorophyll is furnished energy of the proper frequency for carbohydrate manufacture.

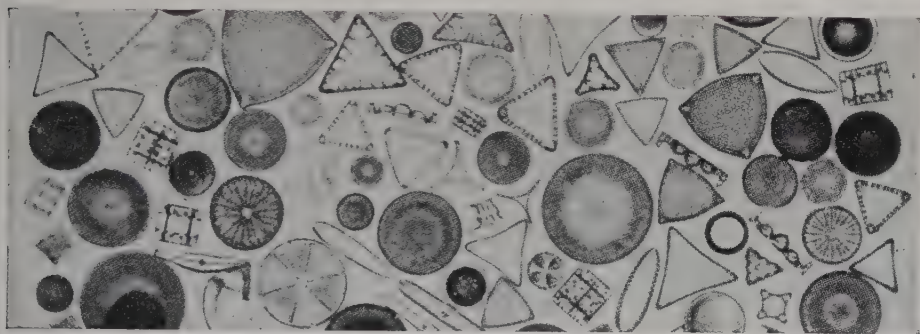


Fig. 10. A photomicrograph of diatoms—tiny one-celled plants which are very closely related to the sea-weeds

green algae never occur at any great depth except in tropic seas with sandy or coral bottoms, where light penetrates to considerable depth without much interference. For the most part these forms occur on the surface or in very shallow water. The brown algae are found at somewhat greater depths, more frequently between tide levels, and the red algae will thrive at greater depths than either of the others. The brown and the red pigments appear to play an important role in adapting these forms to growth at greater depths. They have the property of fluorescence by means of which they can absorb light of one frequency and emit it again as energy of a longer wave length. In photosynthesis it is the radiant energy of

Although none of the algae have any great direct economic use, it must be remembered that their indirect economic use is of tremendous importance. They compose the flora of the seas and fresh water environments. Thus they constitute the one source of carbohydrate food available for aquatic animal life. For the most part, the smaller animals feed on the microscopic plants; somewhat larger animals, such as small fish, eat the smaller animals; and so on, ad infinitum. An interesting case of one of our largest animals feeding directly on microscopic plants is that of the baleen whale which feeds on smaller sea life including the diatoms. As he swims along the surface with his mouth open, the whalebone screen



Fig. 11. Familiar forms of fungi

over his throat catches these small bits of sea life and holds them until they can be ingested. Other forms of marine life may feed directly on the larger algae. All in all, the algae constitute the "pastures of the sea."

FUNGI: The fungi are much like the algae in organization, although there are no forms among them which reach the size of the brown algae, nor the complexity in structure of many of the algal types. The greatest difference between the two groups is an absence of chlorophyll in the fungi. Because of this they are unable to synthesize carbohydrates, hence are dependent on other sources of organic food. They obtain this material from the tissues of living plants or animals, and are called *parasites*, or from the partially decomposed remnants of dead plants or animals, in which case they are known as *saprophytes*. They are primarily terrestrial forms.

In the parasitic relationship, the synthesized food used by the parasite disturbs the metabolic balance of the host, or the presence of fungal tissue serves to interfere with the normal functions of the host, bringing about a diseased condition. A large number of the plant diseases, such as mildews, smuts, and rusts, are due to fungal growths. Animal diseases of this type are rather rare and are usually of the nature of skin infections, such as the so-called "ring worm." The economic loss due to diseases of our cultivated plants and timber are so great that the study of these forms (plant pathology) has become one of the most important branches of plant science. In this work the methods are principally preventative rather than curative. They consist largely of spraying with chemicals which damage the fungal

tissues and prevent their development, or of breeding strains of cultivated plants which are naturally disease resistant. Use is also made of quarantine in an effort to prevent the introduction of disease fungi into uninfected agricultural regions.



Fleischmann Laboratories

Fig. 12. The effect of yeast is clearly shown: the bread on the left was baked with yeast, that on the right without it

The principal groups of saprophytic fungi are the *molds*, which cause fermentation in food products, and which also attack such organic products as shoe leather; *yeasts*, which bring about fermentation in sugar solutions; the *bracket fungi* of the forests, which aid in the decay of dead trees; and the group designated as *mushrooms* and *toadstools*, some of which are edible.

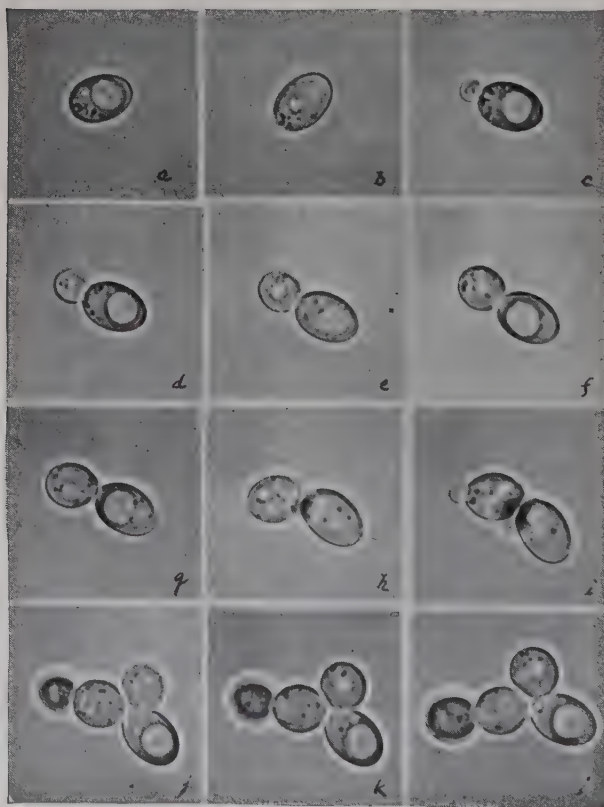
In most of the fungi the tissues which carry on the vegetative functions are composed of threadlike filaments similar to the filamentous algae. By means of these filaments the plants absorb and transport their food. They grow by forming new cells within the filaments and reproduce by means of spores. These are borne in specialized reproductive structures which are commonly combined with vegetative tissues to form fruiting bodies. An ex-

ample is the umbrella-shaped part of the mushroom or toadstool. With any one of these, well opened and mature, it will be found possible to shake countless numbers of spores from its lower surface. Other examples are the black, blue, or yellow powdery portions which characterize molds. In all of these it will be found that the vegetative tissues penetrate the substratum on which the fungus grows. The spores are set free to be distributed by air currents. Any one of them falling in an environment where the temperature, moisture, and other conditions are favorable will germi-

nate, that is, will grow into a new filament which is the beginning of a new plant body. If this filament can find its way into another living organism, or if it comes in contact with organic matter, it will continue to grow and will develop into new vegetative tissue which will eventually form a new fruiting structure. In addition, some fungi have a sexual reproductive process but it is not of great importance to their existence.

Not all fungi have a vegetative structure of the type described above. The yeasts, for example, are unicellular organisms which grow by a process

of budding and reproduce by means of spores which are formed inside of any vegetative cell. The yeasts also serve as an example of a fungus which is of great economic value rather than a source of loss or danger. These forms have the ability to carry on *fermentation*, that is, to break up sugar into alcohol and carbon dioxide. If certain of these yeasts are placed in grain extracts or in fruit juices, and the alcohol is allowed to accumulate, beer or wine is formed. If allowed to stand for some time in dough, the carbon dioxide generated makes the dough porous, or "raises" it, and the following baking evaporates the alcohol. Another example of the economic use of a fungus is the employ-



Fleischmann Laboratories

Fig. 13. The budding of yeast cells. These pictures, showing the cells magnified many hundreds of times, were taken at fifteen-minute intervals

ment of certain molds to give the characteristic taste to some of the so-called "fancy" cheeses. In this process the molds play a larger role than the bacteria previously mentioned as of some importance in this connection.

Fungal plants of a slightly different order are the lichens. The most common forms of lichens are the grayish-green, leathery growths which occur so commonly on ledges and on exposed slopes. In addition to these encrusting types, there are others which are found growing on tree trunks in the woods, and the northern forms known as reindeer moss.

The lichen is in reality a dual organism. The leathery body is composed of the tissues of a fungus, and imbedded among the fungal filaments are many one-celled green algae. The fungus parasitizes the algae to the extent of deriving its carbohydrates from them, but this parasitism is not sufficiently extensive to greatly interfere with their normal growth. Furthermore, the algae, as well as the fungus, derive some benefit from the association, since the fungal tissues furnish both moisture and protection to the algal cells. One might say that the fungus pays for its board by furnishing lodging and a supply of water for its host. This type of association between two organisms, in which the organisms are intimately associated and mutually dependent, is called "symbiosis." The lichen furnishes an excellent example of the association, since the fungus, lacking chlorophyll, could not live an independent existence, while the algae, although capable of supporting themselves, could not live independently in the dry environment which is inhabited by lichens.

Reproduction in the lichens takes place in two ways. In the first, the



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Fig. 14. A lichen of the genus *Usnea*, which beards the trees and low growths in cold swamps in the North

fungus matures to form spores. These are distributed by air currents, and if, soon after germination, they find the proper species of algae, a new lichen will be formed. A more common, and more certain method, is a fragmentation of the lichen, in which small pieces of the fungus containing a few algal cells are blown to new localities, where they lodge in crevices and grow to maturity.

In addition to serving as examples of an interesting ecological relationship, these plants play a very important role in nature. They are able to grow on bare windswept ledges, or other exposed situations, where no other plant life can exist. Hence they usually constitute the first vegetation on slopes that have been denuded of soil by erosion. Growing in such places they accumulate soil particles and add to these the *humus*, or decaying organic substance, which results from their own decomposition.

In this way they begin to form a new soil which eventually is sufficient in quantity to support other forms of plant life. They are the pioneers of plant migration into regions previously bare of plants. The capacity of these plants for growth under severe conditions is remarkable. Professor L. M. Gould, on his sledge journey southward from the base of the second Byrd Antarctic Expedition, found lichens growing on the denuded ledges of Mt. Nansen within five degrees of the South Pole. The reindeer moss of the northern arctic regions is a very important source of food for its namesake, the reindeer.

MOSS PLANTS

This group includes the common mosses of damp woods and worn-out pastures, and another less common form, called liverworts.

The liverworts are small leaflike organisms growing closely appressed to damp soil in ditches or in damp woods. Their name is derived from the fact that in some species the leafy body resembles the human liver in shape. In general their organization is more complex than that of the thal-
lus plants, yet they have no true roots or stems.

The mosses have a somewhat more complex structure, since they possess root systems and stem systems of a simple type, and leaves which are quite similar to the leaves of our common seed plants.

These forms are of no economic value but are of interest because of their method of reproduction. This can be best explained in the case of the moss, although it is similar in the liverwort. Mosses do not form seeds but owe their distribution to spores which are broadcast from the small

stalked capsules (sporangia) which may be seen terminating the leafy branches. One of these microscopic spores, coming to rest in moist soil, germinates to form a green branching filament quite like some of the filamentous algae. This is called a *protonema*. After growing through the soil for a while, it sends off branches which develop into simple root systems, and others which form aerial shoots with their primitive leaves. At sexual maturity, sex organs form among the leaves which terminate the shoot. An egg is formed within a microscopically small, flask-shaped organ and sperms are developed within a somewhat similar structure. Eventually the sperms are set free and, being motile because of their cilia, they can move about in the thin film of moisture retained between the leaves. They swim down the neck of the tiny egg flask and one of them fuses with the egg cell. The fertilized egg then develops into a stalked sporangium in which a new generation of spores is formed.

In the mosses there are represented two distinct types of reproduction. The protonema and leafy shoot which bears the gametes constitute the sexual generation, referred to by the botanist as the *gametophyte* (gamete plant), whereas the tissues arising from the fertilized egg produce spores, reproductive cells which form new individuals by an asexual process, i.e., without the stimulus of fertilization. The tissues which give rise to the spores compose the asexual or *sporophyte* (spore plant) generation.

The complete process of growth from the spores of one generation to the spores of the next is called the *life cycle*, or *life history*, of the organism and, since the spore plants are

formed from the fused gametes, while the sexual plants develop from the spores, we speak of it as an *alternation of generations*. This type of life cycle is found among many of the thallus plants and is characteristic of all of the plants of more complex organization. In the case of the mosses and liverworts, the spore-bearing generation is dependent on the gamete generation for its moisture and most of its food. Although some forms have chlorophyll in the tissues of the spore-bearing capsules, in no instance can the sporophyte exist for any part of its life independent of the gametophyte.

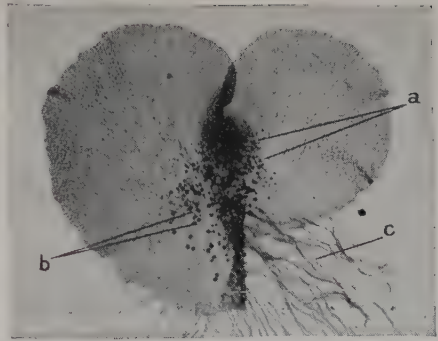
FERN PLANTS

With the ferns most people are more familiar, although the small herbaceous growths typical of our



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Fig. 15. The dark, firm leaves of the Christmas fern remain green throughout the winter, making it a favorite among ferns used for decorating the home



Popular Educator Library

Fig. 16. Prothallus produced from a fern spore; a, archegonia; b, antheridia; c, rhizoids

temperate zones do not represent the best development of these plants. In the tropics, where the growing conditions are more suited to this form of life, many of the ferns grow to be trees sixty feet or more in height. These are known as *tree ferns*.

In organization the ferns are as complex as any of the plants, with true roots, stems, and leaves. In our common types, however, the stem commonly grows underground and only the leaves are seen. In the roots, stems, and leaves the tissue structure and specialization is more like that of the seed plants, but the method of reproduction is by spores, and to that extent they are viewed as more primitive.

The small brown spots, or stripes, which occur on the under side of a fern leaf are clusters of spore cases, each containing a number of microscopic spores. The spores are set free by the breaking of the sporangial wall and are distributed by air currents. By germination, any one of them may form a green heart-shaped body about a quarter of an inch in diameter, growing closely appressed to the ground, and appearing something like

a liverwort. This is called a *prothallus*. On its under side, it bears male and female reproductive organs, much like those described for the moss, and the fertilization of the egg takes place in much the same way as in the mosses, the sperm swimming to the egg in the thin film of moisture which adheres to the prothallus. The fertilized egg then develops into the fern plant with which we are familiar, and, at maturity, the leaves bear new spores. The life cycle is much like that of a moss plant excepting for one difference. In this case, instead of the spore-bearing generation being completely dependent on the sexual plant, it lives an independent existence for most of its life, since the prothallus withers away soon after the young sporeling develops its own roots and leaves. The significance of this difference will be realized when the life cycle of the seed plant is considered.

Other forms of plant life classed as fern plants are the common ground pine, or club moss, and the horsetail. In both cases the vegetative organization and the reproductive methods are so like the ferns that it is unnecessary to describe them. The horsetails have a peculiar habit of strengthening their stems by secreting silica in the cell walls. For this reason they have served pioneer people as convenient instruments for scouring kettles and pans and have received the name "scouring rushes."

SEED PLANTS

The seed plants are of two kinds, those which bear their seeds in cones and are therefore known as *conifers*, and those which possess flowers, so are called *flowering plants*. Examples of the former are such trees as the pine, fir, spruce, and larch. The flow-

ering plants include, not only the forms which constitute our garden and weed flora, but also the "hardwood" or "deciduous" trees like maple, elm, and beech, all of the orchard trees, and the rushes and grasses of meadow, field, and lawn.

These forms are characterized by a complexity in vegetative structure and a specialization in function which is not attained in any other plant group. In general, this complexity is not so great in the conifers as in the flowering plants, but in both groups there are special tissues, some for transporting water and dissolved mineral substance; others for the translocation of elaborated food; protective tissues, such as epidermis and bark; and mechanical contrivances for the control of evaporation. Most of them possess chlorophyll and can manufacture their own carbohydrates and other foods, although there are a few saprophytes like the white Indian pipe of our woods, and a few parasites such as the dodder, which sends haustoria into the tissues of clover, alfalfa, and other green plants. There are also some partial parasites like the mistletoe, which is green, yet is dependent on the live oak for part of its sustenance.

To understand the reproductive process in a flowering plant it is necessary to describe the flower. On the top of the flower stalk is a more or less globular capsule called the *ovary* and in the complete flower this is surrounded by a circle of stalked pollen-bearing sacs called *stamens*. The ovary, or in some cases the ovaries, and the stamens, compose the essential reproductive organs. In some forms they constitute the whole flower, but more often they are surrounded by an inner circle of colored

leaflike organs called the *petals* and an outer set of green leafy parts called the *sepals*. The ovary bears on its tip a region called the *stigma*. This may be a part of the surface of the ovary but more often is separated from it by a stalk called the *style*. Ovary, style, and stigma together compose the *pistil*. Enclosed within the tissues of the ovary are small more or less oval-shaped masses known as *ovules*. Each of these contains a spore which develops into a tissue of a few cells that contains the egg. Within the stamen cavity are pollen grains which also represent spores, and each of these goes through a process of development which results in the formation of two sperm nuclei.

Manifestly the method used by the mosses and ferns for the fertilization of the egg can no longer be employed. The sperm cells have been reduced to simple nuclei enclosed within the walls of the pollen grain, and the egg cell is shut up within the ovary. Fertilization can be accomplished only by moving the pollen grain to the ovary and, by some means, transporting its contents to the egg.

The problem of transporting the pollen to the ovary is solved in several ways. In some flowers which are pollinated by their own pollen (self-pollinated), the pollen simply falls to the stigma or is rubbed upon it by movement of the stamens. More commonly the pollen of one flower is not potent for the fertilization of its own eggs, or even for eggs in flowers on the same plant, but must be carried to flowers on other individuals of the same species (cross-pollination). In the flowers with few or no outer floral envelopes, the pollen grains are usually small, and so light in weight that they can be easily transferred



U.S. Department of Agriculture

Fig. 17. A flying bee with a small amount of pollen already placed in the basket of the hind leg. The pollen may be seen at the lower end of the tibia

from one plant to another by the wind. On the other hand, many flowers have large floral envelopes and larger, sticky pollen grains. In these cases pollen distribution is carried on by insects, usually winged insects especially adapted for the purpose. As a rule the adaptation is mutual, for the shape of the flower and the arrangement of its parts is often closely adjusted to pollination by some one type of insect. As a matter of fact, in all nature there can be found no better examples of adaptation than those between the flowering plants and insects. In connection with this mutual adaptation, the bright colored floral envelopes and the flower odors both play a part. The odors are due to the presence of volatile oils in various parts of the flower. Of course the real attraction for the insect is the presence of food in the form of a rather concentrated sugar solution called *nectar*. This is secreted from glands called *nectaries*. The remarkable feature of the adaptation is that

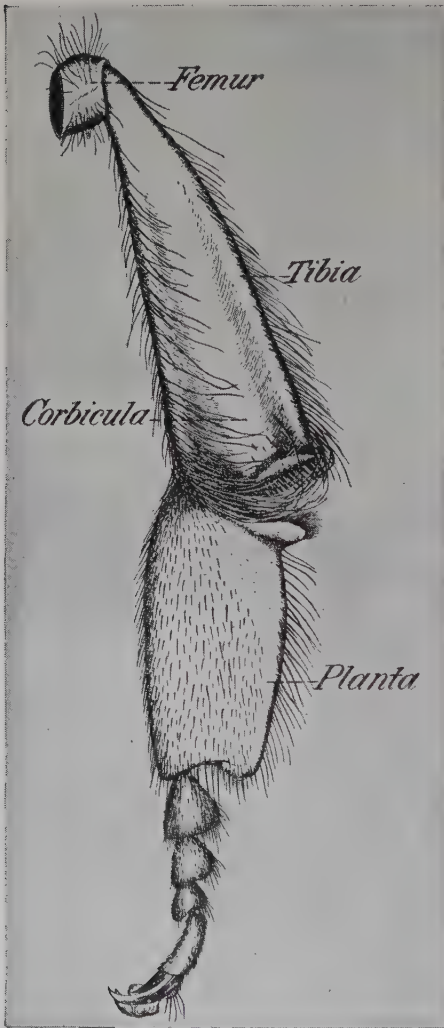
these nectaries are so located in reference to the essential organs, and the flowers are so constructed, that the particular insect or insects which visit them must come in contact with either the stigma or stamen, or with both. The adaptations in the structure of

the insects are often as striking. In considering this mutual adjustment in structure, it is of interest to note that the flowering plants and the pollinating insects have gone through a contemporaneous and more or less parallel evolution.

The stigmatic surface is sticky so that pollen grains coming in contact with it will adhere to it. If the conditions are favorable, and if the pollen is of the proper species, the pollen grains then develop proliferating processes called *pollen tubes*. These grow through the stigmatic surface, penetrate the tissues of the style and ovary, and eventually one of them reaches a small opening in the ovule, whereupon the two sperm nuclei enter the egg-containing tissue. One of the sperm nuclei fuses with the egg nucleus, thus completing the act of fertilization. The other combines with one of the accessory nuclei which have developed in the neighborhood of the egg nucleus.

The fertilized egg nucleus immediately begins its development into the embryonic plant. The other fusion nucleus develops into a tissue which serves as a source of food for the embryo. The ovule in general becomes a *seed* which, when mature, has a more or less impervious seed coat enveloping it. At the same time the ovary begins its development which culminates in the ripe fruit.

Fruits are equipped with specially adapted devices for the dissemination of their seeds, which may be forcibly expelled by a sudden bursting of the fruit, or shaken out to be blown around by air currents, or retained until released by decay of the fruit walls. The fruits themselves may be so constructed as to favor dissemination. Some have winglike appendages



U.S. Department of Agriculture

Fig. 18. Outer surface of the left hind leg of the worker bee. The corbicula, or pollen basket, is an elongated depression running the length of the tibia

SEED DISPERSAL.

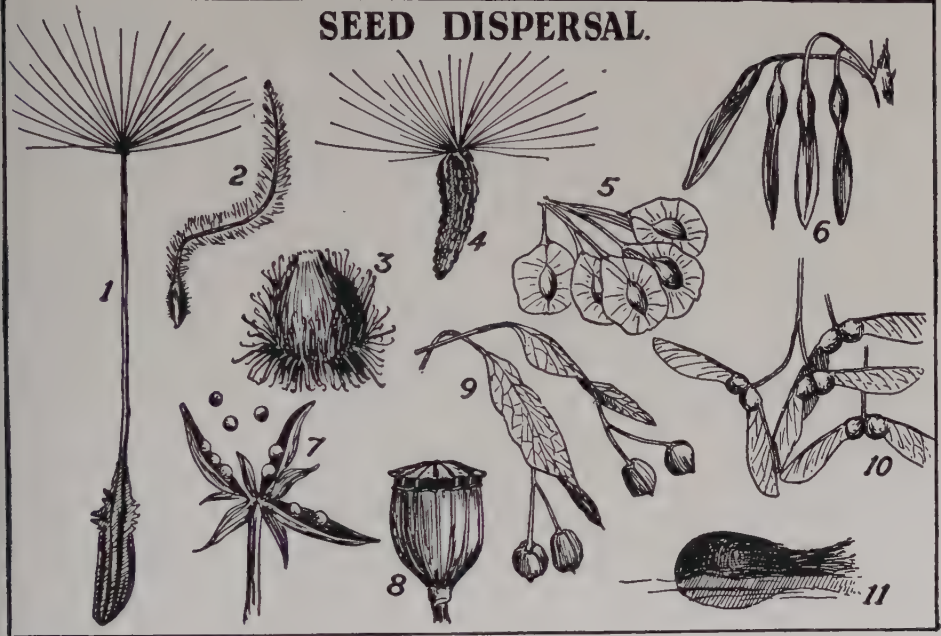


Fig. 19. Methods of seed dispersal: (1) dandelion, (2) traveler's joy, (3) burdock, (4) sow thistle, (5) elm, (6) ash, (7) dog violet, (8) poppy, (9) lime, (10) sycamore, (11) coconut

by means of which they are blown about, others have hooks and barbs on their walls by which they adhere to the hair or feathers of passing animals or the clothing of man, and many have edible flesh. In this type the flesh is usually eaten by bird or beast, and the seed is so resistant to animal enzymes that it passes through the alimentary tract unharmed. Fruits of this type are usually colored to attract the animals which distribute them.

To realize the value of the seed it is necessary to understand that this structure is not analogous to the spore in reproduction. Whereas the spore is a single cell which has the capacity to develop into a young plant, the seed consists of a fully developed embryonic plant, usually surrounded

by the food necessary for its nourishment during its earlier stages of growth, and wrapped up in an impervious seed coat which protects it from desiccation. In addition to this protection from evaporation, the protoplasmic contents of the embryo are by some means able to remain alive in a very inactive or dormant condition. This enables the young plant to retain its vitality under conditions entirely unsuited for plant growth. Not only can it withstand considerable drying out, but it is also unharmed by low temperatures, even those below freezing. In fact, in some seeds freezing appears to be a necessary part of the preparation for later germination. Because of this, the seed plants can exist under conditions which, because of the lack of suffi-

cient moisture, prohibit the growth of spore plants.

If a seed falls in an environment where a supply of moisture is available, it absorbs water, whereupon the embryo within begins to grow and splits the protective seed coat. One end of the embryo grows into the soil to form the root system. The other end, which consists of the first leaves and the growing point of the stem, grows upward through the soil to form the shoot. At this stage the store of food in the seed has become exhausted, the seed coat is discarded, and the young plant, or *seedling*, becomes self-supporting.

Comparison of this method of reproduction with the process in the other types of plants which have been considered, shows that there is no essential difference between them. The more primitive groups are some-

times grouped together as "spore plants," in distinction from those forms which develop seeds. However, they are all spore plants, the real difference being that in the seed plants the spores do not give rise to an independent gamete-bearing organism. In the seed plants the spores are of two sexes. The female spore, retained within the ovule, forms the egg nucleus, and the male spore, the pollen grain, develops the sperm nuclei. The gametophyte tissue, comparable to the prothallus of the fern, or the protonema and leafy shoot of the moss, has now become reduced to a few simple cells which are formed accessory to the egg and the sperm nuclei. The same alternation of generations takes place, but now the sporophyte has become independent for almost all of its life and the gametophyte has become the dependent generation. A transition to this situation is presented in the fern, in which the sporophyte has become largely independent. The additional step accomplished in the seed plant is the dependence of the gametophyte on the sporophyte. Although the seed is thought of as a reproductive structure, it is not one in reality, but represents simply a delay in the process of sporophyte development, a period during which the embryo can withstand the rigors of a season of unfavorable growth conditions.

The process of reproduction in the conifers is essentially the same as that in the flowering plants. The female spore develops into a gametophyte, which is much reduced though slightly more complex than that of a flower, and the male spore is represented by the pollen grain, which also develops two sperm nuclei. In these forms the pollen is distributed



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Fig. 20. The staminate blossoms of the pitch pine, a typical conifer, which give rise to the fertilizing pollen

by the wind and is often adapted for this process by the development of two winglike sacs on its outer wall. The ovules are not enclosed in a flower, but are exposed on the surface of the scales which make up the cone. For this reason the conifers are known to the botanist as the "gymnosperms" (a word of Greek derivation meaning "naked seeds"). In distinction, the flowering plants are botanically classified as "angiosperms" (enclosed seeds). In the conifers the pollen is always borne in separate "male" cones. Carried to the female cones, it settles between their scales and comes in direct contact with the ovules, whereupon a pollen tube grows through the ovule tissues and conducts the sperm nuclei to the egg for fertilization. The process of seed development does not differ essentially from that in the flowering plants, although frequently it requires a period of two or even three years for completion. The seeds of most conifers develop winglike structures on their seed coats, thus adapting them to distribution by wind.

PLANT EVOLUTION

The fundamental assumption of organic evolution is that each plant and animal species now living has been developed from an earlier ancestral form, this in turn from one still older, and so on back through the ages. If it were possible to follow this series back through the succession of ancestral forms which have culminated in our present-day fauna and flora, we might eventually get back to the type or types which constituted the "life primeval." It is not possible to do this because the fossil record, which might tell the story, is extremely incomplete. However, the

fragments of this record which are available do give us glimpses of some portions of chapters in the story of the life of the past, and these can be pieced together to tell part of the story of evolution in its broad outlines.

Here we shall be concerned only with the evolution of the plants. Unless the reader is familiar with the names and the chronological order of the geologic eras and periods, frequent reference to the accompanying chart will be necessary in order to follow and to understand the text. This chart shows the great groups of plants, their probable time of origin, their comparative numbers at various periods in geologic time, as known from the fossil record, and the possible connections between them. In each of the groups, the population at any one time is indicated by the width of the shaded area. For example, the fossil record indicates that in the Paleozoic age the seed-bearing ferns were more abundant than the spore-bearing ferns, but that, as the Carboniferous period began to close, the seed-bearing ferns decreased in number and finally became extinct at about the end of the Triassic. On the other hand, the spore-bearing ferns, although decreasing somewhat in numbers, have persisted to the present, with some increase in numbers during the last thirty millions of years. The broken lines indicating relationships between some of the groups do not in general represent conclusions based upon fossil evidence; they are little more than indications of possibilities. The years assigned to each of the periods represent an approximation, as any measurement in millions of years must be, but they are based upon the conclu-

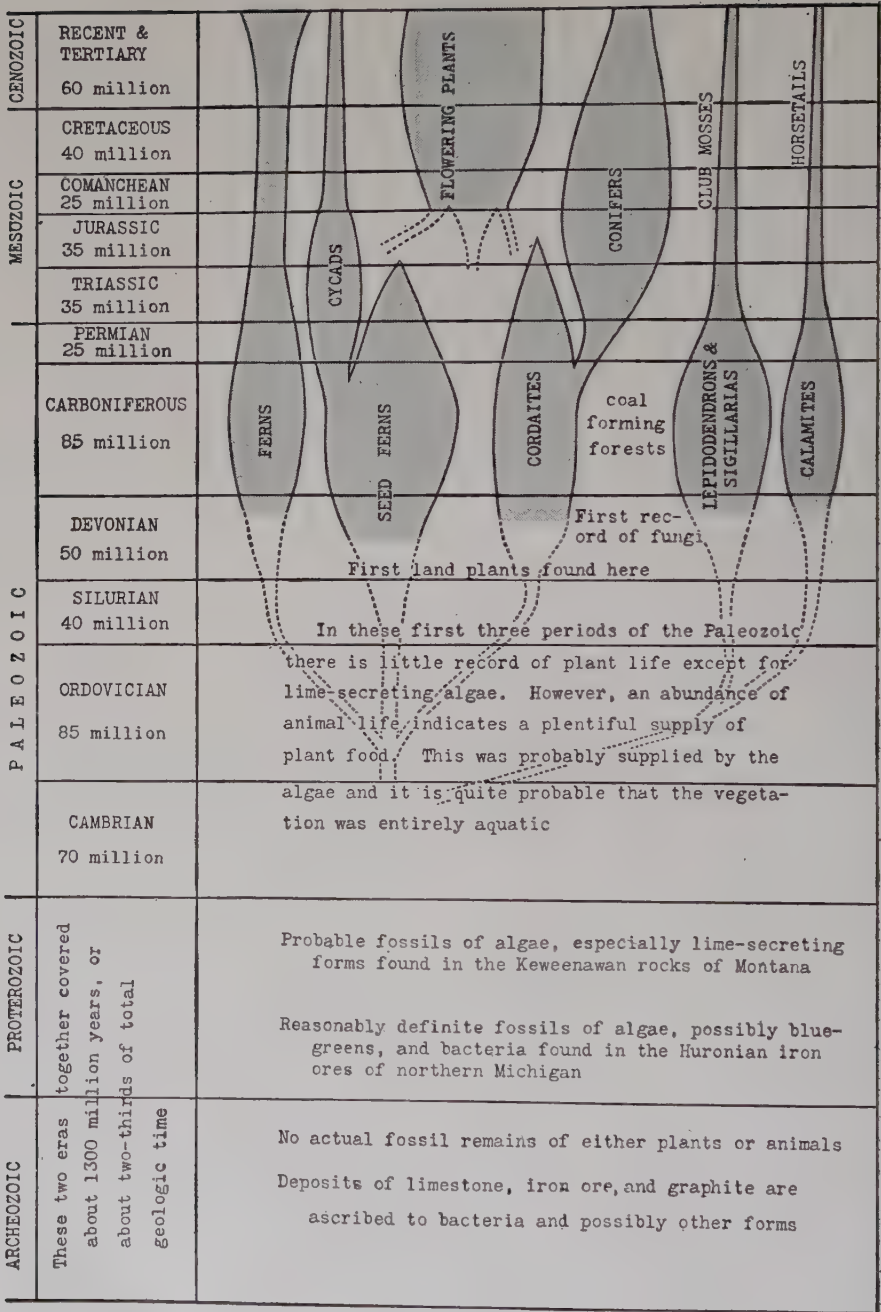


Fig. 21. Chart showing the evolution of plants through geologic time

sions of the geologist and the paleontologist, after extensive investigation of evidence drawn from a number of different sources.

In the earliest strata (Archeozoic) there have been discovered deposits of limestone, iron ore, and graphite, which have been ascribed to bacterial action, and in the Proterozoic there have been found what appear to be undoubted fossil bacteria. Incidentally these are among the earliest fossils known, but, even if they were the very earliest, we should have no sure proof that bacteria were the first forms of life. It might simply mean that they were the first types with sufficient organization to be preserved as recognizable fossils. Organisms are known which consist of a mass of protoplasm with no cell wall. If the original form of life had such a structure certainly it would be difficult for it to become preserved in fossil form. In reference to the whole question, about all that can be said in conclusion is that some bacteria—of iron and sulphur, for example—have characteristics which would make it possible for them to exist previous to the existence of other life, and that there is evidence of bacterial action very early in the earth's history, but that it is entirely possible that simple forms other than bacterial might have constituted the first life.

THE ORIGIN OF CHLOROPHYLL

Since practically all life is dependent, either directly or indirectly, on green plants as a source of vital energy, it is evident that some form of life possessing chlorophyll must have arisen very early in the evolutionary series. When this occurred we do not know, but it is certain that green plants must have been in existence

in the Proterozoic since there are Proterozoic fossils of animals of such complexity of structure as to indicate that they must have derived their energy from green plants. Furthermore, there are fossils which may represent algae that lived during the early Proterozoic, and undoubted fossil evidence of this group in the late Proterozoic. These early fossil algae are quite similar in appearance to the blue-green algae of the present day.

This fact is of considerable interest, and possibly very significant, inasmuch as in the blue-greens the chlorophyll is of a rather simple type and is distributed throughout the cell instead of being borne in chloroplasts as in the more complex plants. It seems as though it were perhaps in forms of this sort that chlorophyll was first elaborated. In them the pigment was present but no carrier for it, the chloroplast, had been developed. Another point of interest in regard to the blue-green algae is their close resemblance to the bacteria in structure, especially in cell organization. It is almost as though they represent descendants of bacteria which in some way developed the ability to form chlorophyll.

About all that can be said in regard to the blue-green algae is that they have a sufficiently simple structure to indicate that they may well have been among the earliest plants. They may represent the progenitors of the other types of algae but there are no types which appear to form a transition between the two groups. In fact, a study of the vegetative and reproductive morphology of the algae indicates that the green, brown, and red algae probably had independent origins, with the multicellular types in each group developing from uni-

cellular organisms which, in many respects, were nearly animal-like.

The earliest fossils of the more complex algae are of lime-secreting forms. Among the existing algae, the types which possess the ability to secrete lime in their tissues are mostly green algae growing in the warm tropic seas, although there are some members of the other groups which have the same habit. The primitive types which were preserved as fossils seem undoubtedly to have been marine algae, but whether they were green, or some other color, is not known. Furthermore, a fossil record of this sort must be interpreted with caution. One must keep in mind that calcification is an ideal habit for fossil preservation, and that these calcified algae probably represent only the ones which were preserved out of a host of forms which failed to become fossils because of their delicate structure.

ORIGIN OF LAND PLANTS

As far as fossil evidence is concerned, the flora of the Cambrian, Ordovician, and Silurian periods has left almost no record, despite the fact that a long time elapsed during which great thickness of sedimentary strata were laid down in various parts of the world. This situation seems especially strange when we consider that during those same periods the animal life became wonderfully developed and diversified, the last of these periods witnessing the beginning of backboneed animals. Since the food of these animals is directly or indirectly supplied by green plants today, it is fair to assume that the same type of food was necessary then. Presumably there was an abundant flora at that time, at least in the sea, and

the gap in the record is due to lack of fossil preservation. This absence of a record of plant life in the first three periods of the Paleozoic is all the more surprising when we consider that in the fourth period, the Devonian, we find a fully developed land flora with a great variety of kinds and a complexity of structure which approaches that of our modern forms.

Most authorities are agreed that plants had their first development in the water and that the land plants which later clothed the continents were developed from the aquatic forms. The well-developed land flora of the Devonian indicates that these forms must have left the sea long before the records show it. The problems to be solved in the change from an aquatic to a terrestrial life were several. First of all, was the necessity for the development of a more or less protective outer tissue. This presented quite a problem because such a tissue needed to be sufficiently impervious to water to prevent too much evaporation, yet it had to be porous enough to allow for the exchange of gases taking place in the processes of photosynthesis and respiration. Other problems arose in connection with the necessity for lifting the food-making parts into the sunlight, and closely connected with this the development of supporting tissues to maintain this position and conducting tissues to transport raw materials and food. Also, as the reproductive organs were elevated into the air, new methods for the transfer of sperm to egg became essential. The result of the solution of these problems, and many others, can be seen in the structure of our plants of today, but no one knows the exact story of the various adjustments.



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Fig. 22. A forest of the Middle Devonian looked like this. The shells in the foreground are cephalopod and brachiopod remains which have washed ashore

THE FIRST LAND PLANTS

The exact nature of the first land plants is not known. Doubtless there were several forms and the experiment of terrestrial life may have been tried several times, sometimes meeting with success and sometimes with failure. Among the fossil forms of the early Devonian there are two which seem to be suggestive of earliest land life. These have been named *Rhynia* and *Hornea* and they are so generalized in structure that they show characteristics of algae, mosses, and ferns. They are in habit typical, upright, land plants with stems from four to eight inches high, yet with neither roots nor leaves. They have creeping underground stems bearing absorbent hairs, but not regular root systems.

The stems have simple conducting tissues, and bear at the tips of some of the branches simple spore cases containing spores. In their general structure they almost suggest algae which have come onto land.

Although these early forms were of a simple type, the land flora of the Devonian in general was by no means so. By the Mid-Devonian there were ferns not unlike our modern types, except that many of them were tree ferns, more like our present tropical forms. These plants, known as *Lepidodendrons*, were undoubtedly the ancestors of our present-day club-mosses, yet, whereas our modern forms are a few inches in length and largely decumbent, their progenitors were trees commonly growing to heights of 80 and 100 feet. Our exist-

ing horsetails represent the decadent descendants of another type, *Calamites*, which grew to be 60-foot trees in the Devonian forests. These were all spore plants, but there were, in addition, two seed plants—seed ferns—which bore no flowers but formed seeds directly on their leaves, and the *Cordaites* which were ancestors of our conifers.



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Fig. 23. Four calamites stems uncovered in Arizona. The two smaller were found near St. Johns; the larger ones are from the Petrified Forest

In the Devonian strata are found the first records of fungi. They exist usually as typical fungal filaments in fossilized plant tissues, and reproductive structures occasionally have been found. It seems safe to state that they were probably present in considerable variety in the early Paleozoic, at least. As to their ancestry there is no fossil record, but a study of the morphology of their vegetative and reproductive tissues brings to light so many resemblances to the algae that they are generally looked upon as

algal forms which have adopted a dependent mode of life, and lost their chlorophyll through degeneration. Of course it is just as possible that they first lost their ability to form chlorophyll and then became adapted to life by assuming a saprophytic or parasitic habit. There is the third possibility that the algae and fungi represent divergences from a common stock, one line developing chlorophyll, the other failing to do so. The principal argument against this idea is that the two lines show a more striking parallelism than would be expected in divergent groups.

ORIGIN OF THE SEED PLANTS

There seems to be little doubt that reproduction by spores, without the formation of seeds, is more primitive than the seed habit. As a means of reproduction it is in many ways just as efficient, but it has the disadvantage of being dependent upon a moist habitat to a much greater extent than the seed habit. In fact, before plants could become adjusted to terrestrial conditions of any great degree of dryness, some other means of reproduction was necessary. As long as the spore germinated to form an independent prothallus like that of the fern, there was no chance of the plant growing in any but a moist habitat, for a film of moisture was necessary for the sperms to swim to the eggs. If the spore germinates in any but a moist habitat, no prothallus is likely to form, or if it does form, no fertilization is likely. In order for the plants to have any habitat other than one entirely restricted by the moisture factor, some solution of this difficulty must be found.

The problem was solved by retaining the female spore on the parent

plant, upon which it depended for its food, and which protected it. Here, within the tissues of the parent, it developed into a prothallus which had become reduced to a few cells. In this situation the old method of water fertilization is no longer feasible and we find the pollen grain being transported to the neighborhood of the female egg, to which its sperms are conducted through a tube. With this, one of the chief problems of terrestrial existence is solved. There remains only a refinement in methods of protecting the developing embryo, in ways of transferring pollen, in devices for making fertilization more certain, and a greater and greater specialization in tissues to better adapt the forms to their environment.

Exactly in what form this device called the seed was first developed, we do not know. As far as the fossil record is concerned, the first indication of it is in the seed ferns and the cordaites, but we know that neither of these groups was able to continue in existence much beyond the Paleozoic. Whether the modern seed plants are descendants of these first seed plants, or whether they represent a new experiment in seed formation, is not known. The fossil record again fails to show the transitional stages.

The forests of the Carboniferous, which formed the rich carbon deposits that we call coal, were of essentially the same types as described for the late Devonian times, although



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Fig. 24. A restoration of a Carboniferous landscape. The most abundant plants are representatives of the seed fern and true fern genera. The other plants include *Calamites* (right margin) and *Cordaitea* (next to *Calamites*)

they were more rich in forms and probably formed a more vigorous and abundant vegetation than any the world has witnessed since. The evidence is that the climate was very favorable, with mild uniform temperatures, an abundance of moisture, and possibly a richer supply of carbon dioxide in the atmosphere. It was this growth which was repeatedly inundated by continental oscillations in elevation. This resulted in an immense accumulation of vegetable matter, which was slowly changed into coal by the great pressure of the overlying strata and the heat of mountain building through millions of years.

As the Paleozoic merged into the Permian, there came a great period of disturbance which resulted in extensive continental uplift, the draining of inland seas, the formation of land bridges, the isolation of seas and oceans formerly joined, and a lowering of temperature which brought on one of the most extensive periods of glaciation.

With these changes in physical environment there were naturally radical changes in the flora of the continents. Many of the older forms began to disappear and some of the newer forms began to rise to dominance. In general, it was a period of transition from a fern plant to a coniferous flora. Many of the former type continued to exist, even as they have to the present time, but many of them are no longer known except as fossils of those earlier horizons. The conifers, which had begun in the Devonian and continued to increase through the rest of the Paleozoic, became more numerous and more diversified. One group of seed plants called *cycads*, became the dominant flora of some regions.

It is represented today by the cycad palms of the tropics and subtropics. It would seem as though it were the seed habit which favored the steady increase of these forms over all others in their competition for existence. Yet the seed-ferns had completely disappeared by the end of the Triassic. Possibly the fact that the coniferous forms did not have the delicate foliage of the ferns may have been a greater factor in this case than was the seed structure.

ORIGIN OF THE FLOWERING PLANTS

Throughout most of the Mesozoic there was no great change in the plant life except within the groups already established, but toward the close of that era, in the Lower Cretaceous, there appeared the beginnings of a new group, the flowering plants. As far as fossil evidence is concerned, this great group seems to have sprung suddenly into existence, full-fledged as it were, during the earlier Cretaceous. This sudden advent of well-developed forms suggests that there must have been a long period of earlier evolution of the group—a period for which we have, as yet, no fossil evidence. Our first records of these forms show such full development toward our modern types that most authorities feel that the real beginnings of the flowering plants probably occurred in the Triassic or even earlier.

The groups from which these flowering plants took their origin are not known. There has been much speculation and controversy, but this particular problem appears to be nearly as far from solution as it was when it was first recognized. That there are possibilities of relationship to different groups is indicated in the chart

by broken lines extending toward these groups.

From whatever forms they originated, the flowering plants were apparently much better adjusted to their environment than any other form, for they thrived so vigorously that by the close of the Cretaceous they had come to be the dominant class. The evidence all goes to indicate that the hardwood trees were among the first to be established, but that the herbs and grasses soon began to form a conspicuous part of the flora. As far as the record can be interpreted, the center of flowering-plant development appears to have been in the northern part of the northern hemisphere, both the northern continents being populated by plant migrations from that center. In general, the tropi-

cal regions are the home of the more ancient forms. Apparently, in the less severe conditions of those regions, the old forms are well able to hold their own, but in the more rugged conditions of the temperate climate they have little chance in competition with the flowering plants, which are so well adapted to withstand seasons of unfavorable growth. Some of these adaptations are seen in the habit of enclosing the seed in a fruit, and in the habit of shedding the foliage in winter. The fullest development of this latter provision is seen in the annual herb which can sacrifice all its active tissues each autumn, yet form so many resistant seeds that it has not only been able to hold its own in competition with its neighbors, but has frequently driven them out.

CHAPTER 19

THE SIMPLER SORTS OF INVERTEBRATES

LIVING examples of the stages of evolution—the story of how mankind and all the other animals reached their present conditions—may be seen around us in the world today. We have the specks of protoplasm, the one-celled animals, and those of many and specialized cells. We have animals with backbones; the fishes and the reptiles; and examples of those that learned to fly. Finally, we have the higher animals, descendants of

those mammals from which the apes and mankind arose. Tracing these sources backwards by the “testimony of the rocks,” by studying the fossilized remains of prehistoric life and comparing them with the life histories of creatures living today, we gather the facts about the story of life. In gathering these facts, geologists, students of the rocks, and zoologists, students of animals, have worked together for a common end.

By studying the rocks in which the fossils are found, the geologist is enabled to name the period during which any extinct animal lived. He is able to tell us, for instance, that 4,000,000 years or more constitute the age during which the mammals, or animals that suckle their young, have been dominant in the animal world; that before them the dominant creatures were the great reptiles. That earlier still there was a period when the most important animal life consisted of fishes and amphibia.

Before that was an age when no backboneed or vertebrate animals had appeared, when animal life consisted—so far as the scanty fossil record shows—mostly of brachiopods (lamp shells), crinods (sea lilies), and trilobites. These last, named “tri-lobites” because their bodies consisted of three lobes, were curious crustaceans that spent their time crawling or swimming slowly along the bottom of the sea.

In the earlier rocks there are but few remains of animal life because most of the living creatures of those days were soft-bodied jellyfish and

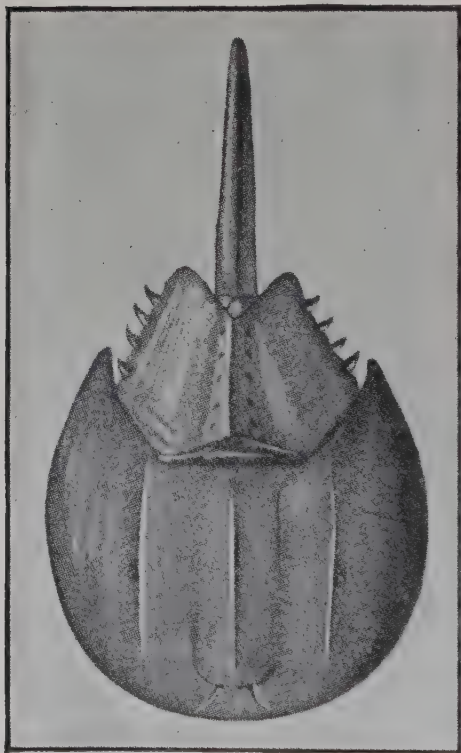


Fig. 1. The Asiatic king crab, a living survival of the prehistoric trilobites. A similar king crab is found on our eastern but not on the western coast

microscopic creatures such as those found today in the scum of freshwater ponds. Some of these creatures had shells that dropped to the bottom of the sea as they died, and thus built up chalk cliffs, such as those of the English coast. In the earliest rocks of all, there is no trace of life.

Although the rocks show us that one "age" followed another, all the types of animals of the previous age did not die out immediately, nor, in fact, did one geological age follow sharply on another. For instance, even today, there are "living fossils," or representatives of those creatures that were dominant in ages of the past. Living representatives of the trilobites of early times are the curious king crabs or horseshoe crabs which are not now regarded as crabs (crustaceans) but as more closely related to the scorpions and spiders. It is a curious fact that these creatures are found today only on the *eastern* coasts of North America and of Asia, now widely separated but united in a circumpolar continent in prehistoric times.

LIVING FOSSILS

On great oceanic islands are also found strange relics of prehistoric eras, such as the komodo dragons, giant reptiles of the Dutch East Indies, and the giant marine iguanas of the Galapagos Islands off the west coast of South America. Such living fossils have survived because their haunts have been cut off from the rest of the world, so that predatory creatures have not been able to enter their lands and exterminate them.

The advancement and adaptation from the earliest forms of life to man has not been a direct ladder of progress, as some people have considered



N.Y. Zoological Society

Fig. 2. The komodo dragon, also called a monitor, is a survival from the distant past

evolution to be. We can picture it better by thinking of a tree with many branches, some of which have ceased growing, while others are now flourishing as specialized groups of animals, such as the mammals, the birds, the fishes, and the reptiles. Certain branches appear to have ended blindly and abruptly if conditions changed and became unfavorable for their continued existence. For example, the giant reptiles became extinct when environmental changes made their life impossible, not necessarily by any sudden change, but by constant and persistent changes going on age after age in the world.

Our tree of evolution starts then with such simple forms of life as the *protoczoa*, or single-celled animals. It then grows through such forms as the *coelenterates*, vase-shaped or cup-

shaped animals like the hydra. Having branched off into such simple forms as the sponge colonies and the much more highly organized *echinoderms* ("spiny-skin"), e.g., the starfish, it passes through the worms (*annelids* and many others) to the *mollusks* or "shellfish" (snails and oysters, for example), to the *arthropods* ("jointed foot"), such as crabs and lobsters.

Progressing upwards, it branches off to the various groups of *vertebrates*, the lowest of which are the *fishes*. They show a big improvement over the other creatures in having a backbone. Their bones are attachments of muscles and their growth is unhampered by a hard shell such as is developed in crabs, lobsters, beetles, and other *Arthropods*, all of which require a protective armor for their soft bodies.

Further progress is indicated in the *amphibians*, such as frogs and newts, which live first in water and then on land. They are followed by the great branch of *reptiles* which are capable of living permanently on dry land.

These three fairly primitive types of backboned animals just mentioned did not inhabit the air, but from the reptiles, there branches off a flying variation, the *birds*.

Meanwhile evolution has produced in the *mammals* a much better form of land vertebrate than the reptile. With the mammal we reach the top of the tree, for today we are living in the age of mammals, of which man himself is, in certain respects, the most highly developed.

This tree of evolution gives us a useful classification of the animal kingdom, and that is exactly what naturalists have done with the 800,000 species, and more, of animals known to science.

Any system of classification must be universal and capable of being used by naturalists in all parts of the world, hence, as we have seen, Latin names are employed by common agreement. The Latin name tells us more than the popular name, as, for example, in the case of *Felis leo* and *Felis domestica*, from which we see at a glance that the lion must be related to the cat, since both belong to the same genus, *Felis*. The addition of a third part to the scientific name means a variety or sub-species. For example, *Pinicola enucleator leucura* (Müller) is the pine grosbeak, variety *leucura* (meaning "white-tail"), named by the ornithologist Müller. If *enucleator* had been repeated, the bird in question would have been the typical form of that species.

Animals normally breed only with their own species. For example, in dogs, retrievers may cross with Airedales, pointers, and setters, as these are all varieties of one species, the dog. Only occasionally has a dog been mated with a wolf, or with a fox.

PROTOZOA

The simple, one-celled animals at the bottom of the animal tree of evolution may easily be seen with a microscope in almost any sample taken from the slimy surface of plants or stones in any pond or ditch. One of the simplest appears as translucent specks of jellylike matter, slowly moving by expanding and contracting.

These *amoebae* have no fixed shape as have the higher animals. They are seldom more than half a millimeter in diameter and move by pushing a bit of the body out on whichever side conditions are most attractive, at the same time drawing in the opposite side. When feeding, they simply en-

gulf their food by flowing the body around it, thus ingesting or swallowing it.

To prevent its protoplasm, or living matter, from flowing idly away, the amoeba has a less-fluid coat of jelly. In the main part of the body is a spherical spot. This is the nucleus, or life center. Also inside the amoeba is a transparent space periodically expanding and contracting, called the "contractile vacuole," an excretory organ by means of which waste matter is got rid of. Other spherical cavities are the "food vacuoles," in which the tiny creature holds and digests its food. In reproducing, the amoeba merely divides, the nucleus splitting first and then the surrounding protoplasm, so that one amoeba divides into two young amoebae. Barring accident, therefore, the creature never dies. Infancy automatically results from old age or maturity.

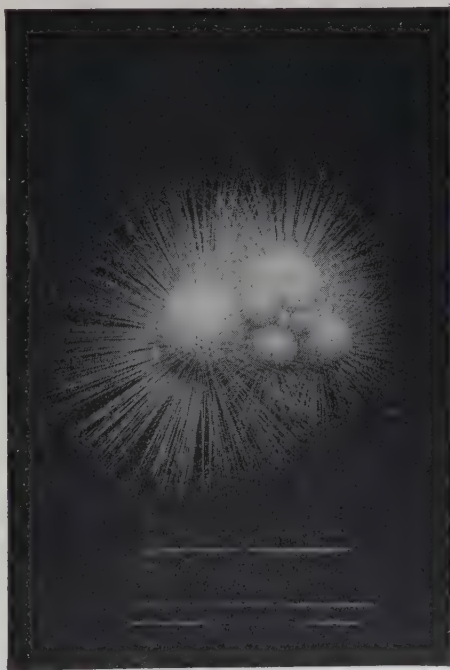
If its water habitat should dry up, the amoeba can *encyst*, or remain almost dried until returning moisture brings back its natural conditions. Encysted amoebae may be revived from pond weeds if placed in a glass of water and left for a few days.

In the life of the amoeba we see the beginnings of animal life, but other animals are considerably more complex. For instance, most of the higher animals cannot split into two for reproduction. They have produced a type of cell from which can grow all the other special types of cells that go to form one of the higher animals, whether frog or bird, snake or man. This germ cell, one of the marvels of nature, is the basis of sex, the reproductive medium of the higher animals, and the cells are handed down from generation to generation with the factors of heredity

contained in them. The amoeba itself has no sex—it is asexual, that is to say, there are no male or female amoebae.

An amoeba, as we have seen, is a single cell, a blob of protoplasm or living matter, having a nucleus of central control. Its contractile vacuole continually swells as it fills with water saturated with waste chemical matter (comparable to urine), and then bursts at the surface and expels this waste. To move, an amoeba merely stretches out a finger of protoplasm in one direction, and the rest of its body "flows" into it. To feed, it merely engulfs its food, into a vacuole, then digests and absorbs it.

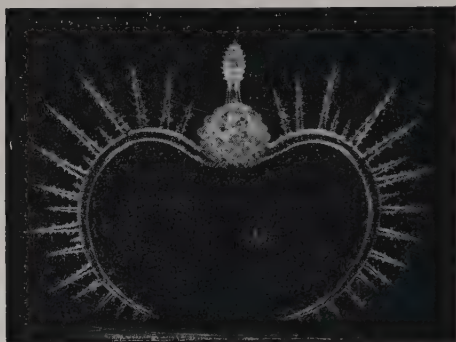
So simple is the amoeba of the animal kingdom that some of its rela-



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Fig. 3. A glass model of one of the Foraminifera. The hair-like projections are known as pseudopodia

tives are claimed by botanists. The slime fungi, or *Mycetozoa*, that cover damp logs, are an example. As with other fungi, if their haunts dry up, their spores germinate to produce a mass of amoebalike protoplasm that feeds and divides like the amoeba of



American Museum of Natural History

Fig. 4. A glass model of a radiolarian (*Dorcadospyris dinoceras* Haeck)

the ponds. The white corpuscles in our blood are also amoebalike, one-celled organisms.

Amoebae belong to the *Rhizopoda*, or single-celled animals having unstable body shapes. On the other hand, the *Foraminifera* of the sea have tiny, oval, perforated microscopic shells from which protrude their *pseudopodia*, or footlike branches of protoplasm.

In fresh water there is the egg-shaped *Gromia*. From the mouth of the oval, horny shell the protoplasm protrudes and flows around it, sending out a delicate network of branching pseudopods full of streaming granules and occupied with capturing and engulfing food particles. Chalk cliffs consist of masses of the calcareous shells of *Globigerina* and other rhizopods that lived in the primeval seas. Countless shells dropped to the ocean floor when the earth was cool-

ing and the land masses forming, and these built up the chalk hills.

The *Radiolaria* have beautiful, flinty skeletons shaped in marvelous trellislike forms and other intricate patterns.

In addition to the rhizopods, there is another group of single-cell animals, the *Infusoria*. They have more stable shapes and are covered with waving fields of delicate, slender, hairlike protoplasmic appendages called—as in plant organisms—*cilia* (from our eye-lashes). They can be quickly bred from an infusion of hay in water. They subsist on dead and decaying vegetation.

Flagellata have small, whiplike appendages by which they travel through the water. One of the more fascinating members is *noctiluca*, a minute kidney-shaped animal with a flagellum rising from the center. These creatures cause a phosphorescent glow on the water whenever, as often happens, they swarm in myriads.

The cilia surrounding the bodies of Infusoria serve to move them and also to sweep in food. Included among the Infusoria, or Ciliata, is the little slipper-animalcule, *paramecium*, easily bred from an infusion of hay. *Vorticella* is another infusorian resembling a little bell that grows on a stalk attached to pondweed. The bell is not hollow, but is filled with protoplasm with a collar-shaped rim covered with cilia. Within it is a large, bent, rod-shaped (macro-) nucleus and a much smaller micro-nucleus.

SPONGES

Another colony of little polyplike marine animals, which, as it were, live in one great house, or flat, is the

sponge, which brings us to the many-celled animals. If we cut through an ordinary bath sponge, we see it is a gristly mass crossed with channels. In the sponge pockets live the lowly animals, tentacles of which keep a constant current of water passing through those channels, thus bringing in food and carrying out waste material.

COELENTERATES

The inhabitants of the rock pools, or the ponds where children paddle on their seaside holidays, are always interesting to the scientist. There are the jellyfish, floating platelike creatures with stinging tentacles hanging down in a bunch. Their life story is another surprise, for the egg drifting in the sea becomes attached to the

bed where it grows up into a cuplike column with a fringe of tentacles (Fig. 5). The cup divides transversely till it resembles a stack of saucers, each of which floats off into the sea, turns over, grows a bunch of tentacles from the middle, and so forms the large jellyfish we see drifting with the current.

The corals are formed by polyps. These are small cylindrical animals attached at one end to the sea bottom. The free end is surrounded with a fringe of finger-shaped tentacles, and the mouth is at the center of this free end. The attached end secretes and builds up a hard structure of calcareous matter. They increase in number by budding or by dividing lengthwise and build up great reefs and atolls like great community flats.



Fig. 5. Living coral polyps photographed under water at Tortugas. Note the protruding tentacles



Fig. 6. This remarkable series of photographs shows a sea anemone (one of the polyps) engulfing a fish

FLATWORMS

Among the various phyla of small lower organisms unscientifically called worms are the Flatworms, of which there are three classes: (1) non-parasitic ("free-living") flatworms such as *Planaria*, (2) trematodes, parasites, such as the liver fluke, (3) tape worms, or cestodes, also parasites.

Planaria and many of its relatives are found creeping over stones in streams or ponds. Its mouth, just as in coelenterates (jellyfish), is in the middle of its body, but it has a head and tail and creeps head first by means of waving fields of cilia on its belly. Its stomach or intestine is highly branched; and it has no anus (intestinal vent), which is true also of the jellyfish. In the head is a pair of ganglia, from which nerve cords run back to the tail, one on each side of the body, almost uniting behind to make a complete ring. In this respect it is not very different from a jellyfish, but its body is bilaterally symmetrical, as explained above, not circular and radially symmetrical as in the coelenterates. It is one step higher in evolution.

The *liver fluke* lives as an adult in the bile ducts of the liver of sheep, swine, and cattle. Its mouth is at the head end, in the middle of a sucker; back of the mouth is a second, or ventral, sucker by which the worm clings to the wall of the bile duct. Between the two suckers is the opening of an elaborate reproductive system (both sexes in one individual) through which the eggs pass out. One fluke may produce a half million eggs, and the liver of one sheep may be infested with more than 200 flukes, so that the chances are good for one sheep to be the "host," as a para-

sitized animal is called, of a hundred million eggs.

These eggs pass down the bile duct into the sheep's intestine and out with the feces. In water they hatch into a cilia-covered embryo, which dies unless it happens to swim into the breathing pore of a certain kind of snail. In the snail's body it forms a saclike cyst within which, by budding, a motile, wormlike embryo (redia) is developed, with a sucking mouth and pair of elbows at the hind end, by which it works its way out of the cyst. In this redia's body, there develops by budding another kind of wormlike embryo (cercaria), a little more like the adult in that it has two suckers and a long tail. Escaping from the mother redia through its thin wall, the tailed embryos scull their way out of the body of the snail itself and through the water of the wet meadow to a blade of grass, to which they cling by the sucker, cast off their tails, and remain encysted until they happen to be eaten by a sheep, or other herbivorous mammal. Escaping from the cyst, the young fluke in the sheep's intestine crawls up into the bile duct where it lives happily ever after.

The chances that many of the hundred million eggs from the original sheep will become mature worms are small indeed. Damp pastures and plenty of the right kind of snails greatly improve the chances.

In the Orient, various kinds of flukes are transmitted to people by eating incompletely cooked fish. Flukes of many genera and species infect not only the liver ducts of man and other animals but also the lungs and veins. Human blood flukes are a serious source of disease in Africa and rice-growing regions of Asia. The



Fig. 7. *Taenia saginata*, the beef tapeworm, which makes its home in the intestines of man where it attaches its suckers to the wall of the lining

sexes are separate; the cylindrical female carries the slender, diminutive male within a groove along her ventral side; hence the name "schistosomes," or split-body, is applied to this group of curious and dangerous flukes.

Taenia solium and *Taenia saginata* are two common tapeworms in man's intestine, living on the food there and growing by budding more segments. The head of the pork tapeworm, *Taenia solium*, is furnished with a ring of twenty to thirty hooks and four suckers to prevent its being swept away from the intestine wall by the passage of food. The beef tapeworm, *Taenia saginata*, much more common in the United States, lacks the hooks but has four suckers. Specimens of

Taenia solium quite commonly measure two or three yards in length. The beef tapeworm is usually from four to eight yards long, rarely ten yards.

Every day a pork tapeworm may cast off fourteen segments, each containing at least 8,800 eggs, so that one of them would produce 80,000,000 eggs a year. Their life history begins in the stomach or intestines of pigs or cattle which accidentally swallow tapeworm segments or scattered eggs. Within the intestines the eggs develop into motile embryos with three pairs of clawlike appendages. By means of these sharp organs the embryo bores through the wall of the intestine of the pig or ox into the blood vessels and finally into the muscles. Here in the flesh it forms an oval cyst, within which the head of an adult worm develops, curiously enough inside out (suckers within). Then the head pops out, properly everted with suckers outside, extending out from the cyst. This is the "bladder worm" stage embedded in beef or pork. Eaten in imperfectly cooked meat, the head attaches itself to the wall of the man's intestine, and the segmented worm grows out from it. New segments form next the head, the oldest are at the free end.

NEMATODES

The roundworms, or threadworms, are a phylum of importance, for some of them are serious human parasites. Many burrow among, or into, the roots of vegetation. One of the parasites of man in the southern states and in tropical countries is the hookworm.

It is only about three-eighths of an inch long, the female being a little longer than the male. It crawls about

in the intestine, sucking blood and causing anemia. The eggs pass out with the feces, and the young worms live in polluted soil. Infection comes chiefly by penetration of the young worms through the skin of bare feet or hands.

The mouth of the tiny worm is on the top of its head, relatively large and provided with sharp teeth, admirably adapted for boring and sucking. It can be destroyed by the use of certain drugs, and prevented by careful sanitation and the wearing of shoes.

The next worst roundworm pest in America is the minute *Trichinella*, infection with which comes from eating poorly cooked pork. The female worm is only one-eighth of an inch long and the male is less than half her size. In the "measly" pork are cysts containing immature worms, which are set free in the human stomach and intestine. There they become mature within a couple of days and the females are fertilized. Then the viviparous females bore into the wall of the intestine and scatter their microscopic young into the blood vessels and lymph spaces. In the blood these young ones are distributed widely into muscles rich in blood vessels, such as the diaphragm, eye muscles, and tongue, where they become encysted among muscle fibers, just as occurred in the pig. The disease, called trichinosis, begins a few days after eating the infected pork, when the adult worms are present in the intestine; still worse are the pains when, during the second week, the young are being circulated through the blood stream into the muscles. Once encysted in man, nothing further can happen to the worms, since human flesh is rarely eaten by car-

nivorous animals. Pigs get it from eating rats, uncooked entrails, or other offal.

A large roundworm found especially in the tropics, but everywhere that unsanitary conditions of soil and water occur, is *Ascaris*. It is as large as the earthworm and its species-name "lumbricoides" means that it superficially resembles the jointed worm which will be described in the next section, but, like all other roundworms, it is unsegmented. The female worm is about 9 inches long, the male 6 inches.

These unpleasant creatures come from the eggs, swallowed in drinking water or infected vegetables, which hatch in the small intestine. The young migrate through the intestinal wall and other tissues, clogging blood vessels of liver and lungs. Finally,

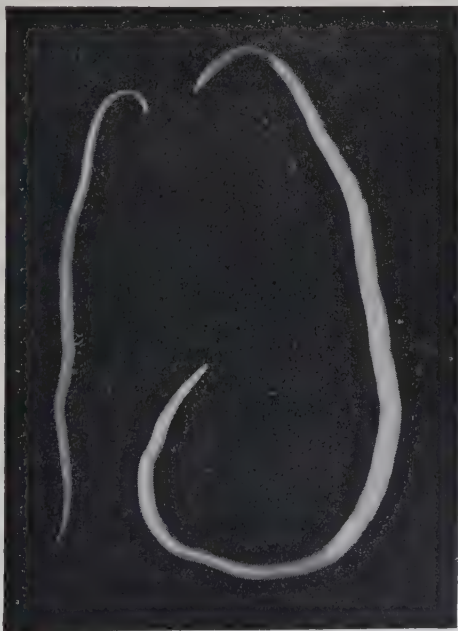


Fig. 8. Two roundworms of swine. The larger one is female, the smaller, male

when mature, they work their way back into the intestine and cause all sorts of discomfort which are difficult to treat.

A very similar species occurs in the pig, and others in the dog. One from the horse has become celebrated among biologists because of the studies that for a long time have been made of its developing eggs, which are admirably adapted for examining the changes going on in the nucleus of dividing cells.

The hairworm, or horsehair snake, found in stagnant pools, has been traditionally and incorrectly supposed "to come from a horse hair." As a matter of fact, the female lays long strings of eggs on water plants. When these hatch, the very young worms swim around till they can climb into an aquatic insect in its early (larval) stage. When the latter (such as a mayfly, dragonfly, beetle) matures and goes ashore, the parasitic young worm goes too. Escaping from one of these unwilling "hosts," the still minute worm somehow gets into a cricket or grasshopper (perhaps through its breathing pores), where it lives in the blood of the body cavity until large enough to get its own living in a pool. Naturally, wet weather and temporary pools in meadows are helpful in its distribution.

ANNELIDS

Annelids, or segmented worms, are well represented by the common earthworm. As a phylum, they are a step higher, or more complex, than the flatworms and roundworms and are a sort of introduction to the great jointed-foot phylum (arthropods), which includes centipedes, insects, crabs, etc. The annelids have soft bodies unprotected by coats of mail

such as those covering the bodies of the arthropods.

The earthworm's skin has to be kept moist, so one finds earthworms only in wet soil. They come up from their burrows to the surface at night, or in cloudy, rainy weather. Strong light drives them down into their narrow burrows, which, in moist weather, extends only a foot or two below the surface. Cold and drought, however, make them retreat deeply into the soil, where they pass the winter.

On each segment of a worm are pairs of setae or bristles. When the worm moves through the soil, it expands the forepart of its body, grips the soil with the setae, and then draws up the hind part of the body. Releasing the setae gripping the soil at the front, it grips the soil at the rear and moves forward again. Clinging to the mouth of the burrow with the tail end, the head extends out to collect bits of leaf which are dragged below for food.

Decomposed leaves are their chief bill of fare. Their droppings, piled up at the mouth of the burrow, are a valuable source of humus, or leaf mold. Their useful service to mankind in this respect is well described by Charles Darwin, father of the theory of evolution. In describing the earthworm, he recounts many of his experiments on their habits in foraging for food. Among other things, he measured the quantity of droppings deposited over a square yard in a unit of time, and computed the amount of fresh leaf mold brought to the surface annually, which in many places amounts to one-fifth of an inch.

The sinking below the surface of ancient buildings and monuments, such as the Druid Stones at Stone-

henge, England, he attributed largely to earthworms, though he does not fail to give credit to other agencies, such as dust blown by the winds and the drift of soil in beating rains and other weathering agents.

Darwin concludes that the smoothness of a "wide, turf-covered expanse on which so much of its beauty depends, is mainly due to all the inequalities having been levelled by worms. It is a marvellous reflection that the whole of the superficial mould over any such expanse has passed, and will again pass, every few years through the bodies of worms. The plough is one of the most ancient and valuable of man's invention; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures." He compared their constructive activities to those of the still more lowly organized coral polyps of the tropics which build "innumerable reefs and islands."

Earthworm burrows loosen the soil and allow air to penetrate; fine, mellow soil is largely the result of their castings. All this helps in the growth of roots, though it may be noted that, in the crowded conditions within a flower pot, roots are sometimes injured by earthworms.

In the internal structure of the earthworm, the alimentary tube runs straight through to the end of the tubular body. The front part, or pharynx, is a muscular, sucking organ which grasps bits of leaf during the foraging. The crop stores, and the thick-walled, muscular gizzard grinds

the food, which is further digested and absorbed in the intestine.

There is red blood in the earthworm collected in the blood vessel of the back, or "dorsal vessel," in which it is propelled forward in waves to the "hearts," through which it is driven downward into the lower, or ventral, vessel. Here it flows backward toward the tail and into vessels sending it to the skin for aeration. This redness of the blood is due to the same substance, haemoglobin, which makes human blood red after it has taken up oxygen from the air, but in the earthworm the haemoglobin is not in red cells, or blood corpuscles, as in man, but is dissolved in the blood fluid. There are no gills or lungs for aerating the blood. This is accomplished in the fine blood vessels within the skin. Many of the marine relatives of the earthworm (*polychaetes*), however, have tubular gills on the head region. Others have beautiful, feather-shaped gills in a sort of crown upon the head, which is constantly being expanded and then withdrawn.

The nervous system consists of a two-lobed mass above the pharynx, the cerebral ganglion, or "brain," and a ventral nerve cord on the floor of the body cavity. Between brain and nerve cord are a pair of nerve cords encircling the pharynx.

The earthworm has no eyes, but its body, especially its front end, and to a lesser degree its hind end, is sensitive to light. It is best adapted to (feels most at home in) twilight, coming out from the dense darkness of its burrow in the evening and drawing back at daybreak.

The sense of taste is well developed. Darwin reported that "pieces of raw and roasted meat were fixed several times by long pins to the sur-

face of the soil in my pots, and night after night the worms could be seen tugging at them. Raw fat seems to be preferred even to raw meat or any other substance which was given to them, and much was consumed. They are cannibals, for the two halves of a dead worm placed in two of the pots were dragged into the burrows and gnawed."

Recently, Dr. C. G. Rogers has found, by many experiments, that they take meat and chocolate in preference to apple, turnip, or carrot, and that they take lemon and onion last of all.

Their sense of touch is acute but they are apparently deaf.

The body cavity surrounding the alimentary tube is divided by partitions into sections corresponding to the segments of the body. In each segment the nerve cord is enlarged into a pair of closely united ganglia, comparable to the pair of larger ones in the head on the upper side of the pharynx.

On the posterior side of most of the partitions, or septa, are hung a pair of long, delicate, twisted tubes, which in a primitive way represent kidney tubes. Each has at one end an open funnel passing through the septum into the next segment in front, while at the other end it penetrates the side of the body wall, and opens on the outer surface. The flaring mouth of the funnel in the next segment is covered with vibrating cilia, easily seen with the microscope. These sweep a current of fluid into the tube, which is then propelled along into a bladderlike enlargement, which empties its contents occasionally on the surface of the body. From its resemblance in function to a kidney, the tube is called a nephridium (plural, nephridia).

Earthworms are functional hermaphrodites. Their union in pairs may be observed after a rain in almost any garden. During this union each transfers sperm to the other, which is stored in two pairs of pockets, the mouths of which open on the body surface in front of and behind the tenth segment. Since the sperm-duct openings of each are on the fifteenth segment, the heads of the two worms, as they stretch out from their burrows and meet, are pointed in opposite directions.

A few days later, egg-laying occurs. The clitellum (the glandular, swollen segments, 28th-35th) secretes a membranous ring, containing a milky fluid, which slips forward toward the head. On the way, it takes up eggs from the openings of the egg ducts (14th segment) and then sperm from the two pairs of pockets at the tenth. Finally it is passed forward over the head, and closes to form a capsule. In this, the sperms swimming in the milky fluid unite with the eggs, which then proceed to develop into little worms.

It is alleged that these young worms are cannibals and eat one another until only one remains for, in any capsule picked up under a compost heap, you are likely to find only a single wormlet, the last survivor.

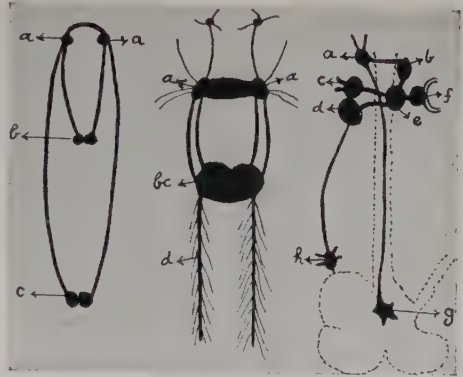
MOLLUSKS

No sub-kingdom (phylum) of animals is better suited for a hobby than "shellfish," as some of them are incorrectly called, none of them having the slightest claim to be known as a fish. Mollusk, from the Latin *mollis* or soft, referring to their juicy bodies, is not a very apt term either, for the jellyfishes (coelenterates) are even softer and the jointed-worms (anne-

lids) are just about as soft, yet no one will question the softness of their bodies. Many of them are protected by some sort of shell. There is not much danger, nowadays, after a little study, in getting them confused with members of any other phyla. Formerly there was some risk of taking the modern lamp shell (brachiopod) and its numerous extinct fossil relatives for a bivalve mollusk, but now we know that even in the lopsided oyster, which is a genuine mollusk, the two shells are on its right and left sides, whereas a brachiopod has one shell on its back and the other under its stomach. This and other anatomical features separate the brachiopods from mollusks and sets them apart as the "mollusk-looking" phylum, or Molluscoida.

The reasons for recommending mollusks as a hobby are both practical and aesthetic. Shells in almost infinite variety of form, already thoroughly cleaned and prepared for study, can be picked up among the algae cast by the waves on any beach; and, as specimens, they have fast colors and are not corrupted by moth or rust, as are so many museum specimens. Their variety and beauty of form and color are a wonderful exhibit of what growth and evolution can do. Backed up by observation of those which can be studied alive in an aquarium, or vivarium, one may get some inkling of how this growth is taking place in the animal itself, how the mollusk lives and moves and has its being.

Many of the most exquisitely beautiful marine mollusks, such as the nudibranchs, covered with brilliantly colored gills, and the squids with their kaleidoscopic changes of color, have no external shells, and to be appreciated must be seen alive.



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Fig. 9. Nervous systems of the Mollusca. At left is *Anodonta* (mussels). *a* = cerebral ganglia; *b* = pedal ganglia; *c* = parieto-splanchnic ganglia. In the center is the genus *Limax* (slugs). *a* = cerebral ganglia; *bc* = pedal parieto-splanchnic ganglia; *d* = nerves to foot. At right is the genus *Sepia* (cuttlefish). *a* = posterior buccal ganglion; *b* = anterior buccal ganglion; *c* = pedal ganglion; *d* = parieto-splanchnic ganglion; *e* = cerebral ganglion; *f* = optic nerve and ganglion; *g* = splanchnic ganglion; *h* = ganglion stellatum

Most zoologists will agree that mollusks and annelids were evolved from the same free-swimming marine ancestors too delicate to have any of their remains preserved in the rocks, but somewhat similar to some of the unsegmented marine worms of today. The reason for this is that the developing eggs and swimming embryos of both groups are extraordinarily alike. The spiral way in which the cells of the developing egg pile themselves together to make a twirling, top-shaped embryo (trochophore) is the same in each. If this embryo secretes a pair of shells upon its sides and discards its head, it becomes a member of the clam tribe; if it buds off, behind, a long string of body segments, it becomes an annelid; if it grows behind

into a long, very simple cylindrical trunk it may become an unsegmented worm, such as *Phascolosoma*, which can be dug up abundantly just off-shore on mud flats. These creatures are sometimes called *sipunculids*, sometimes by an older, more inclusive term, *Gephyrea* (bridge), invented when they were regarded as a link connecting annelids with the starfish phylum—a higher group in the scale of living things.

Characteristics shared by all mollusks are an unsegmented body and a muscular foot on which they crawl



Fig. 10. Anatomy of the oyster lying in shell of left side. The delicate "mantle" covering right side and under the right shell was removed with the shell to show some of the organs. A, Gills; B, Muscle for closing shell; C, Inner surface of left "mantle" and exit for water which has passed through the gills (near by is the anal opening); D, Loop of intestine; E, Stomach; F, Feelers or "palps" which guard the mouth; G, Edge of "mantle" which secretes and widens the shell

(snail), or with which they dig (clam), or grasp their prey (squid, which swims and neither crawls nor digs, but has arms around the head, and a "siphon" behind it to represent the foot). Hanging down from the back, somewhat like a man's coat, is a fold of fleshy skin called the mantle, which not only covers and protects the gills but also secretes the shell. Mollusks have nearly colorless blood, which is collected in a large vein, purified and aerated in kidneys and gills, sent to the heart, which receives it into an auricle (or a pair of them in the case of clams), and poured into a ventricle, which then pumps it around through arteries. All this suggests what goes on in the higher animals (vertebrates), though the blood, when it comes oxygenated from the gills, is blue, not red as in the earthworm and vertebrates. The blue substance, which fades when it gives up oxygen, is called haemocyanin (blood-blue) and it is dissolved in the fluid, not carried by the floating cells (corpuscles) which are white, or amoebalike.

The nervous system is, of course, developed along with the organs which it controls, most highly developed in the lively, big-eyed cuttlefish or in the squid, in which the brain, or ganglion of the head, is much like that of one of the more intelligent insects, while in the poor clam, which is rightly said to have lost its head entirely (no eyes, no tentacles, only a couple of pairs of leaf-shaped feelers near its mouth), the brain is reduced to a mere lump on each side of the mouth, or rather, gullet.

But these head ganglia are chained up with a pair of ganglia in the foot, forming a ring suggesting the nerve ring of a jellyfish, and the part of the ring which includes the foot ganglia

is comparable, in a way, with the ventral nerve chain of the earthworm, so the degenerate nervous system of the clam is not quite as outlandish as it may seem to anyone who is not inquisitive.

To get a birdseye view of mollusks they may be arranged in classes, as follows:

(1) Chitons (*Amphineura*=both-side nerve-cords, referring to their being bilaterally symmetrical).

(2) Snails (*Gastropoda*=“stomach-foot”), a very large group with spiral shells.

(3) Clams (*Pelecypoda*=“shovel-foot,” alias *Lamellibranchia* “plate-gill”).

(4) Squids (*Cephalopoda*=“head-foot”) including the nautilus, cuttlefish, octopus, etc.

CHITONS: The chitons are a small group of straight, symmetrical, flat-footed animals with a jointed shell, made of eight transverse plates along the back, partly covering the mantle which secretes them. The uncovered part of the mantle surrounding the plates (“girdle”) is leathery and, in some species, covered with spines. Between the foot and edge of the girdle are the gills. The jointed shell reminds one of the back of the sow bug, or wood louse, the curious little terrestrial crustacean found under debris in gardens. A chiton, when disturbed, like some of the sow bugs or even like an armadillo, rolls itself up into a ball.

Chitons are common in warm, southern seas, although some are found deep in arctic oceans. Atlantic species are at most not over two or three inches long, in most species much less than that, but the huge Pacific *cryptochiton* is 10 inches in



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Fig. 11. The circulatory system of the snail. *a* = heart; *b* = vessels carrying blood from lung to heart; *c* = lung; *d* = aorta; *e* = gastric cavity; *f* = hepatic cavity; *g* = pedal cavity; *h* = abdominal cavity; *i* = irregular canal communicating with *h*

length; strangely enough its plates are buried beneath the mantle and so are not visible.

SNAILS: While crawling, most gastropods carry their spiral shells pointed upward and backward to the right. In it are twisted their viscera. Also on the right in the land snail, which breathes with a lung made of the veins spread over its mantle cavity, is its breathing pore. This opens and shuts under the edge of the shell.

Looking straight at the tip (apex) of the shell, we see that the whorls twist around to the right, clockwise. The thread of a screw or the turns of a cork-screw do the same. But suppose that we do not look straight at the tip but into the mouth of the shell, with the tip pointing upward, as in many pictures of gastropod shells; in almost every case the mouth of the shell is on the right, which was also the right side of the live snail, or whatever the gastropod may be. This is true even of the cowrie, in which the opening runs the whole length of the shell. Here the spire,

formed when the cowrie was young, is inconspicuous and finally becomes covered by new layers of shell, leaving a pit above the buried spire.

But, as every rule has its exception, so there are left-handed gastropods, just as there are left-handed people. The little fresh water *Physa*, for example, is normally left-handed, a characteristic which can be traced back to the egg itself, and is already determined within the mother's ovary.

Most species of the winkle, or whelk (*Fulgur* or *Busycon*), are right-handed, but there is one in Florida called *perversa* because it persists in being out of style, left-handed. It is a huge, jet-black animal with a dull white shell which is sometimes a foot long. Why the egg, embryo, and snail grow spirally and to the right or left, is a mystery of molecular physics and chemistry not yet explained.

As the shell increases in size, new strips of it are secreted by the edge of the mantle and added to the lip of the shell, so that successively larger and larger lines of growth can be clearly seen in many species. At the same time a new layer—or layers—of pearly material is laid down on the inside of the shell by the outer surface of the mantle. The long spines and other irregularities of the surface of certain shells are produced by irregularities in the edge of the mantle.

In the limpets, the flatly cone-shaped shells which stick so closely to the rocks, the edge of the mantle encircles the whole foot and deposits new rings of lime carbonate around the margin of the entire shell.

In the slug, the shell would seem to be lacking altogether; it is reduced to a tiny, white, thin plate completely covered by the mantle. The mantle itself can be seen as a soft, saddle-

shaped membrane stretched over the naked foot just behind the tentacles. On its right edge lies the breathing pore which opens into the cavity beneath the mantle and serves as the equivalent of a lung.

CLAMS: In contrast to the gastropods which have only a single spiral shell and are hence sometimes called univalves, we now come to the bivalves which have two shells, one on the right and one on the left of the symmetrical body.

Clams and their kind also have a mantle, which hangs down from their backs along their sides. The mantle border, in this case, too, secretes new strips of shell along its edge, and layers of mother-of-pearl are laid down inside the shell by the outer surface of the mantle.

Projecting forward from the under side of the body is the muscular, hatchet-shaped foot used for spade-work in sand or mud, and, between foot and mantle, hang down on each side of the body two fleshy curtain-shaped gills, which are flat bags with openings above, along the line of their attachment to the body. Through minute holes on the surface of the gill, water enters, passes upward through the cavities of the body and out through the upper openings already mentioned, thus aerating the blood circulating in blood vessels through the gill. The water supply is furnished by a siphon at the hind end of the clam, which burrows into the mud or sand with its foot, leaving the end of the siphon stretching out above the surface of the mud to take impure water and to eject water that has passed upward through the gills and picked up waste substances from the kidneys.

This siphon is a double tube made by the fused-together ends of the mantle, with two channels running through it, a lower one bringing pure water in around the gills and conveying food particles forward to the mouth, an upper one ejecting waste water.

The two valves of the shell are hinged together by a tough elastic ligament which, by its elasticity, tends to make them fly open; they are drawn together in a live clam by two strong muscles stretching from one valve to the other. Their attachments, one in front of and one behind the rest of the body, leave scars on the empty shell. In oyster shells, the scar is dark and conspicuous.

Oysters have only one shell-closing muscle. Having adopted a lazy, sedentary life they have no need of a foot, and their ancestors long ago lost it. Their left valve, in which they lie, is deeply saucer-shaped; the right one is a flat, closely-fitting cover of the saucer.

In strong contrast to the oyster, the scallop (*Pecten*) is an active swimmer. It swims by clapping the valves of its shell together and forcing out the water. This drives the animal rapidly in the direction of the hinge. By holding a starfish, its hereditary enemy, near it in an aquarium, a scallop can be chased from one place to another as it attempts to escape.

It has a single, very large, shell-closing muscle, having lost in early life the one which would have been in front. The shell is light in weight and its folds, due to the folded edge of the mantle, may help in directing its movements. Around the edge of the mantle is a fringe of delicate finger-shaped tentacles, along the bases of which are numerous blue

eyes with a lens and simple retina. Just how much they can see is still uncertain.

Another sedentary relative of the oyster is the salt-water mussel, which does not dig but inhabits the surface of rocks, anchored down by tough threads. These are secreted by glands in its foot, which is much too small for digging. Out of the gland it pours a sticky, glue-like fluid along a narrow groove in its foot. Touching the foot to a rock, this glue adheres and hardens; on drawing back the foot, a tough thread is spun. Then the process is repeated until the shell is anchored firmly to the rock by many wirelike strands.

The mussel, however, is not tied down for life to one spot; it can reach out, plant a new bunch of wires further on, and cut the old ones. This,



National Geographic Magazine

Fig. 12. In the South Pacific Ocean native pearl divers risk their limbs and their lives to gather pearl shells on the sea bottom

naturally, is a slow method of locomotion, but it makes possible a better adjustment to the feeding ground, without danger of being swept away by tempestuous waves.

The bivalves are of great economic interest. Oyster culture is fascinating, but we must omit it for lack of space. The soft-shell clam of New England, the hard-shell or little-neck of the Atlantic coast from Cape Cod to Florida, the scallop, and certain species of mussels are important items in our food supply.

An interesting species of angels' wings, the ribbed piddock, is used as food at Havana and is found as far north as Cape Cod. The long, white, ribbed shells are often found on Florida beaches. It burrows deeply into sand, or even into wood or rock, sending to the surface from the narrow, gaping end of the shell an extremely long siphon. It bores downward by turning the shell around on its long axis, and scraping with the edges of the broader end of the shell.

The pearl and pearl button industries are of great importance in certain parts of the world. In upper Mississippi, fresh-water mussels are gathered in vast numbers. In Panama Bay and the Pacific coasts of Central America, of Ecuador, and of Peru, pearl fishing is an active industry. Margarita, an island off the Venezuelan coast named for its pearls (for Margaret means pearl), has been a famous source of these gems for four centuries. The annual income in pearl shell and pearls from that small island is around a million dollars.

But the major part of the world's supply of pearl shell and pearls comes from Australia, the South Seas, Ceylon, and the Persian Gulf. Here the pearl oyster (*Avicula margaritifera*)

grows abundantly, and it is especially in rough places in coral reefs, where growth is crowded and small organisms of many sorts are swimming, that pearls are most likely to be found.

Any small body entangled in the mantle becomes covered with the mother-of-pearl secretion, but the embryos of parasitic worms are now regarded as the particles most likely to be involved. These worms form minute spherical cysts favorable for producing pearls of great regularity of form. The color and brilliance depend, of course, on the nature of the mother-of-pearl itself, which may be black, or of almost any shade of pink and blue.

One danger to which the pearl divers of the South Seas are exposed, a very serious and much-dreaded danger, is that a hand or foot may be caught and held fast by the huge valves of the giant clam, *Tridacna gigas*, which is sometimes two or three feet in length and 600 or 800 pounds in weight. Embedded within a mass of brilliantly colored coral polyps, the wide-open shell is concealed by a fringed mantle which, like its body, is colored the same as its surroundings. The diver needs keen sight and much experience to avoid being caught in this terrible trap, which has crippled or drowned many victims. A huge pearl once taken from a giant clam was found to contain as a core, the foot of an unlucky child.

Contrasted with this colossal monster of the South Seas, the shells of which may be seen in many churches, where they are used to hold holy water, are the tiny fingernail clams, easily found at the bottom of any brook or pond and among the submerged leaves of water plants. Their

shells are smaller than the nail of your little finger. In ripe old age, these diminutive clamlets grow to be three-eighths of an inch long.

SQUIDS: Built for intensely active life at or near the surface of the sea are the head-footed mollusks. These highly organized, flesh-eating brigands are strangely unlike their humble cousins, the clams and snails. With long, sucker-covered arms and in many cases a sharp, birdlike beak, they are able to defend themselves without, in most cases, having to shut themselves up into any shell.

The shells of the squid and cuttlefish are secreted beneath the mantle which almost completely covers them, except that they can draw the head back into it, leaving out only the formidable tentacles. In the cuttlefish, the shell beneath the surface of the back is the soft, white, limy "bone," which is used in bird cages to furnish the canary with necessary salts of lime. The ridges on it mark the stages of growth of the cuttlefish.

The squid's shell is a delicate, flat rod of horny material shaped so much like an old-fashioned quill pen that it is usually called "the pen." Quaintly enough, there goes with it ink, for when the squid is beset by enemies, or otherwise excited, it shoots out from a gland beneath the mantle a cloud of black ink. In this smoke screen, it easily beats a retreat or advances to the attack. The corresponding ink in the cuttlefish takes its name from its manufacturer, *sepia*, the cuttlefish's scientific name, and is the basis of the well-known brown pigment used by artists.

The common squids of our coast vary in size from eight inches to a foot. They swim in shoals and pursue



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Fig. 13. The head of the common squid is not a handsome sight. The tentacles are known as sessile arms

schools of young mackerel, which they seize with their tentacles and bite with their beak. They annoy the fishermen by getting trapped in their nets, but are nevertheless useful as bait. They can be lured and beached by placing strong lights at the bow of a boat and rowing toward shore; cast upon the sand by the receding tide they are helpless.

There are giant relatives of the common squid in the North Atlantic which are sometimes cast upon the shores of Newfoundland. The body of one measured 20 feet in length, beyond which the enormous arms stretched out 50 feet more. Apparently they are common in the deep northern ocean, for fragments of them have been found in the stomachs of sperm whales, and fishermen tell strange stories of struggles they have witnessed between these two leviathans of subarctic seas.

But there are cephalopods with real shells. Of them the nautilus is best known. The shell is a chambered, flat spiral. In the largest and last-formed chamber, lives the animal itself, secreting with its mantle an addition to the shell's mouth. Behind it is a perforated partition, back of which is

the next chamber, which, like all the smaller and still smaller ones, is full of gas. When a new chamber is built and its own body has increased in size, the nautilus moves outward and, with its mantle's surface, secretes behind it a new partition. The shell thus is a most interesting formation.

CHAPTER 20

ARTHROPODS

THE jointed-foot animals (Arthropoda) in some cases look so much like the jointed worms, or annelids, that it is no wonder that the early naturalists called them all "ringed animals" and let it go at that. Even now in everyday parlance we refer to many of the jointed-foot animals as "worms," though zoologically it is incorrect to do so. Caterpillars, really young butterflies or moths, are not worms but arthropods. They have jointed feet—three pairs of them. Wireworms are grubs of beetles, not worms but insects and, of course, arthropods. The young of some insects, such as the wormlike maggots of flies or the fleshy grubs of bees, have no legs, but when they become mature flies and bees, they have three pairs of jointed legs like other insects; in other words, they are arthropods.

To make plain what is included in the jointed-foot phylum (arthro=joint and pod=foot), let us examine a simple family tree which will show the principal groups, or classes, of this enormous phylum, or sub-kingdom, and their relationship to one another.

They probably all evolved, in the tremendously remote past, from annelids, so we will place annelids at the root of the tree from which the five principal classes of arthropods sprang.

Insects alone make up about two-thirds of the grand total of known species, which has been estimated to be around 836,000, but will certainly be nearer a million when, if ever, all the inhabitants of the earth have been seen and described.

Arthropods, in general, are covered with a horny or calcareous coat of mail which is shed periodically as the body gets larger and the coat becomes too tight fitting. They have a heart under the skin of the back, just as in the annelids, and quite unlike the vertebrates; it is either a simple tube (insects, myriapods, and arachnids) or a sac with arteries running forward and backward (crustaceans, e.g. crayfish), but, in any case, it has pairs of openings protected by valves. These admit into the heart pale-colored blood from irregular cavities among the muscles and other viscera—cavities much like lymph spaces in man,

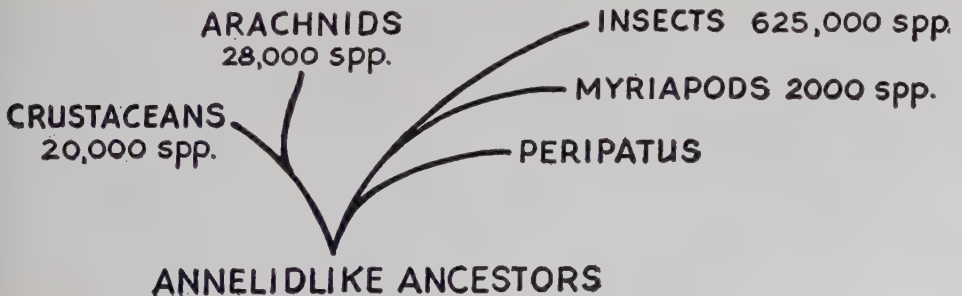


Fig. 1. The family tree of Arthropods

which carry a similar pale fluid called lymph.

The nerve cord runs along the middle of the floor of the body, as in annelids, but, since the body segments are in many cases jumbled together, there is a corresponding fusion of the ganglia (collections of nerve cells and fibers) so that one compound ganglion takes care of several jumbled

body segments. In annelids, each segment has its own separate pair of ganglia.

There are two main lines of descent among these five classes: (1) typically gill, or lung book, breathers and (2) air-tube breathers. The crustaceans, or crab tribe, breathe with gills which have to be kept moist; the arachnoids, or spiders and their kind, have breathing sacs full of minute, booklike leaves that can best be seen on a large scale in a king crab (horseshoe crab), which is not a crab, but nearer a scorpion or a spider, though it lives in the sea.

The air-tube breathers have a pair of spiracles, or breathing pores, one spiracle on each side of most segments. These holes open into a complex system of elastic branching tubes (tracheae) which carry fresh air into every part of the body, aerate the blood, and expel waste gas (carbon dioxide). These air-tube breathers are terrestrial, as a rule, though many insects in early life are aquatic and some take in air through feather-shaped or tubular gills extending out into the water.

It should be acknowledged, too, that some of the arachnoids, the mites and ticks, have lost their ancestral lung books and taken to breathing with tubes, or tracheae.

CRUSTACEANS

When we turn over old stones or lamp logs in the garden, we often find squat little, many-legged grayish creatures usually called sow bugs, wood lice, or pill bugs. Many people assume these to be insects, forgetting that they have too many legs. Although no one would suppose it, they are a link with the seashore—relatives of the crabs and lobsters that, in the long course of evolution, have taken



Fig. 2. Some crabs use a sponge as camouflage, for their enemies avoid sponges in any form. (Above) the crab itself, (below) how it looks when it is clothed in sponge

STRANGE LIFE HISTORIES

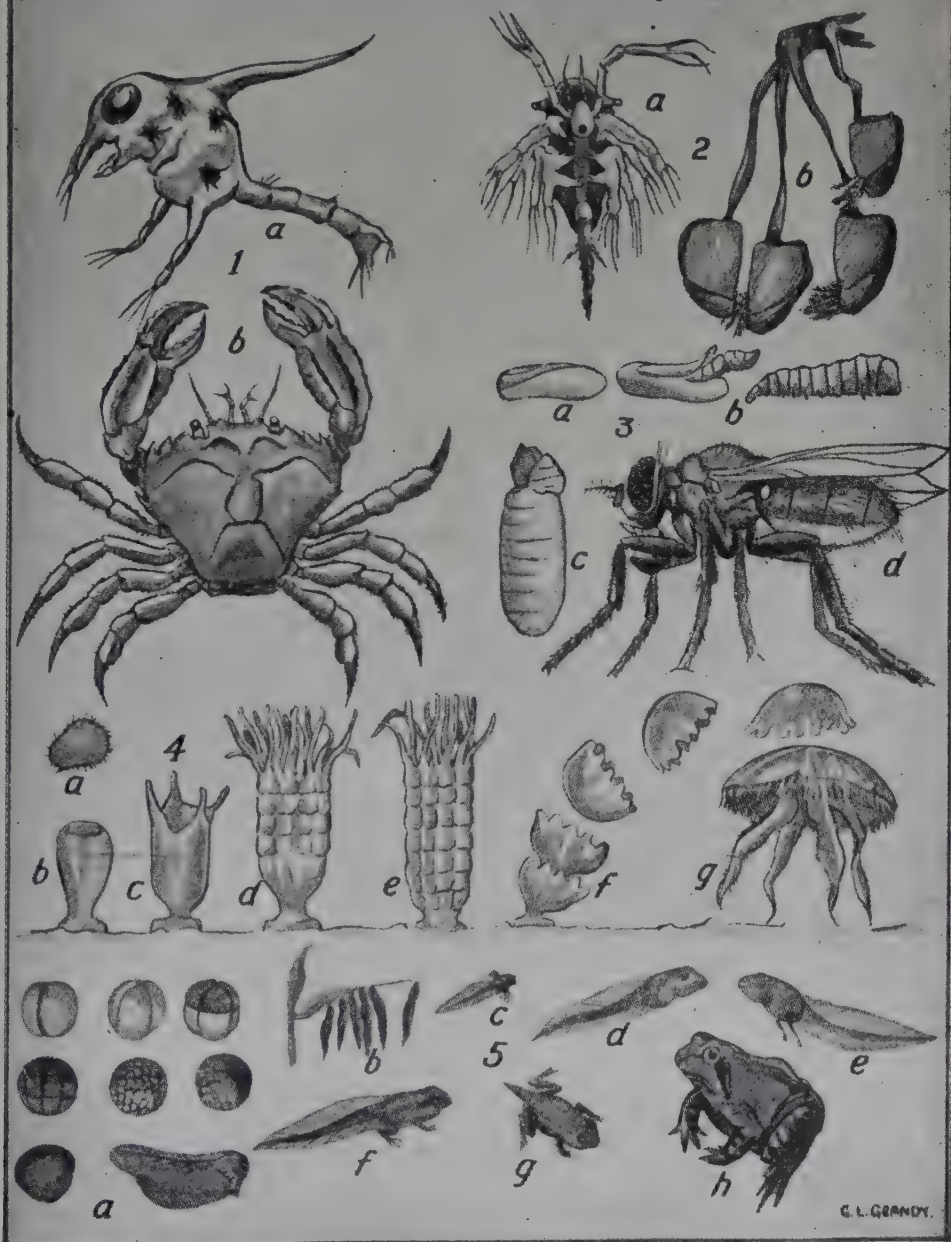


Fig. 3. Life stages of 1. Crab. 2. Barnacle. 3. House fly. 4. Jellyfish, 5. Frog.

to a life in damp spots inland. A study of their structure shows that they are closely related to the shrimps and the sand hoppers of the seashore. Of course, there are many freshwater crustaceans, too, such as the freshwater shrimp and the so-called water flea (*Daphnia*) much used as food for aquaria fishes.

The life histories of crabs and lobsters are among the most fascinating in nature. It is difficult to realize that the active little free-swimming, tailed larva of the crab later sinks to the bottom of the sea owing to the growing weight of its carapace or hard skin, and that it finally ends its days running sideways on the shore. Many other creatures, oysters and mussels, for example, begin life in a free-swimming stage, however, and continue to roam about the water until their changing forms weigh them down to a life on the muddy bottom of the ocean.

The crabs and lobsters, and their relatives the shrimps and prawns, have compound eyes that stand on moveable stalks. This is convenient and useful, since the head is so firmly joined to the trunk that it cannot move by itself. Internally, they have an interesting structure, called the gastric mill, for masticating their food. It is much on the principle of the bird's gizzard, but the chamber has hard plates of chitin on its wall, and these crush the food like millstones.

It is not the whole "back" of a crab that we see, but its carapace, covering head and thorax, which are not separated in the crustacean as in the insect. If we turn one over, we see its abdomen, or "tail," tucked underneath. The lobster, however, has an extended abdomen and crawls about with its body raised on its four pairs of legs, in front of which is a pair of heavy forceps or nippers. Three pairs of jaw-feet behind its mouth

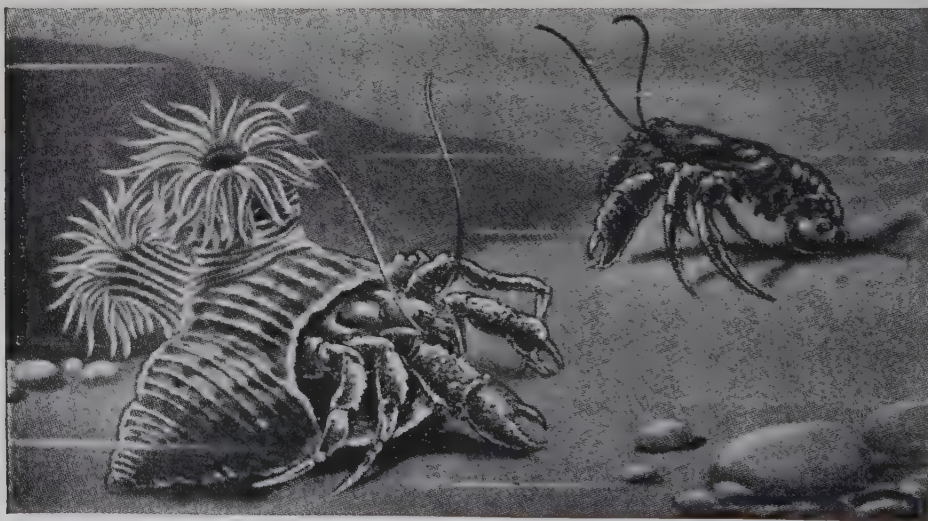


Fig. 4. A hermit crab (left) in its borrowed shell and (right) looking for another shell at molting time. The hermit crab has to find a shell to live in as otherwise its soft, unprotected abdomen is a vulnerable target for its enemies. Sea anemones frequently live on these shells



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Fig. 5. As this picture makes clear, the pincers of a lobster are really a development or adaptation of the fifth pair of legs. The long antenna and compound eye are also important parts of his equipment

kick food into the mouth, and also keep a fresh current of water passing over the gills under the carapace. If it is suddenly alarmed, the lobster claps its tail under its body so vigorously that it shoots backwards into some nearby hole or retreat. Except in some rare, deep-sea, Pacific forms, lobsters are not pink in the sea but a deep bluish-green mottled with greenish color; they turn pink on boiling.

The lobster has two pairs of feelers on its head. On the basal segment (next to the body) of those in front (antennules) there are two whiplash-shaped touch organs, smaller than the single, long feelers (antennae) just behind. In this same basal segment is a cavity containing a sense organ used by the lobster in keeping its balance.

Into it project many sensory hairs to which are glued minute grains of sand pressing this way and that when the lobster swims. In the lobster's early life, this organ is probably more useful than when full grown, when its claws help in balancing just as our arms do in walking. Then the opening into the balancing organ is reduced to a pore admitting sea water.

Periodically a lobster casts off its skin, including the old, balancing cavity, but a new, soft skin quickly hardens. Probably by ducking its head into sand, minute sand grains are again introduced into the cavity.

Certain crabs, soon after molting, have been observed to pick up sand grains and drop them into their open balancing cavity.

The hermit crab is well known for its habit of taking an empty whelk shell to protect its soft abdomen (Fig. 4). Sometimes a sea anemone will live on the whelk shell (Fig. 4) and when the growing hermit crab moves house, it is said to move the sea anemone to its new shell. This is a good example of an arrangement by which different animals live together for mutual benefit. They do not harm each other or live at another's expense as in parasitism; the crab has the advantage of the sea anemone's stinging apparatus which may frighten away foes, while the sea anemone can feed on the scraps remaining from the crab's meals.

A small fish (*Amphiprion percula*) has been observed associated with a huge anemone of the South Seas which is two feet wide across the

disc when fully expanded. The brightly colored little fish has been observed dashing in and out of the big mouth of this polyp. How it avoids the stinging apparatus of the polyp will need further investigation, but at least it has plenty of room in the capacious stomach of its host.

There is also a little oyster crab which you probably have come across in oyster stew. This is a similar case of taking in boarders or, as the zoologists say, "commensalism." The little crab gets his modest allowance of food inside the shell and mantle of the oyster, and, perhaps, eats a few noxious organisms which might annoy his landlord.

Barnacles are really crustaceans which live in little shell-like cases on the rocks and piers, but are free-swimming in their early stages. Later, in their shells, with their bunch of tentacles kicking actively, they whip passing food out of the sea into their mouths.

ARACHNIDS

Spiders, and their allies the scorpions, differ from insects in more ways than in their possession of an extra pair of legs (Fig. 6). They have no separate head nor antennae, and their simple, single eyes are on the same body portion as their limbs. Not all the fifteen thousand known varieties of spiders spin webs. That habit belongs to a special web-making group, and the web is not the spider's home, but its snare. In the distant past, the spiders that lined their retreats with silk may have left a stray strand or two over the edge, and by this a fly was accidentally entangled. From this they may have developed the habit of leaving strands and increasing them to catch more flies, and

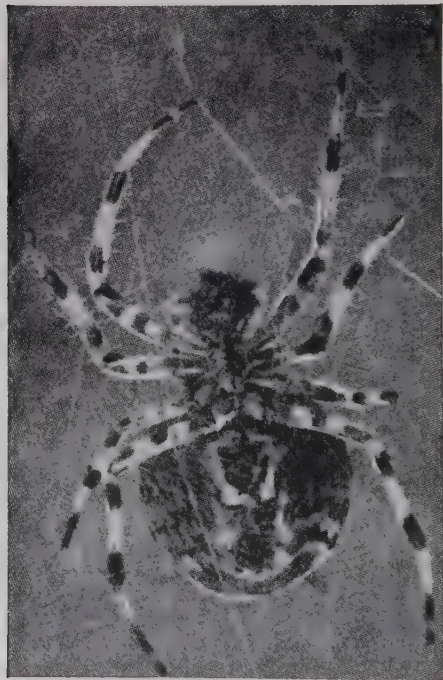


Fig. 6. The garden spider spins its web

gradually the web-making habit reached its present proportions.

A typical spider's web consists of twenty-six, opaque, radial threads and twenty-four transparent transverse ones on which are drops of viscid fluid to catch the prey. The average web contains 87,360 globules of this sticky fluid, but a large one of 14-16 inches diameter may have 120,000. Such a web may be made in 48 minutes and it is so light that 27,600 webs weigh one pound. The thread is so fine that a ball of thread the size of a pea could be unwound and stretched from New York to Washington.

Because spider threads are finer than the thinnest strands of platinum wire, they are used by scientists for marking the sight-lines on telescopes, microscopes, and theodolites. A famous optical works used to send a man to collect spiders and gossamer. The captive spider was put in a box, and



Anders & Co.

Fig. 8. A close-up of the Tarantula, front view

when released, spun a thread to lower itself to the ground, but as fast as it spun, the thread was wound round a wire frame. A hundred yards of thread, or twenty frames full, could be obtained from a single female spider. Such a thread marks the meridian at Greenwich Observatory in England.

Gossamer is the autumn production of young spiders that climb onto a fence, spin a thread by which they anchor themselves, then spin lengths of double thread into the breeze. This pulls like a parachute until eventually the young spider bites through the anchor thread and floats away to new haunts.

In addition to the web spiders there are the interesting water spiders. They arrange a big bubble of air in the pond weeds for their young (Fig. 10). The big bird-eating myga-

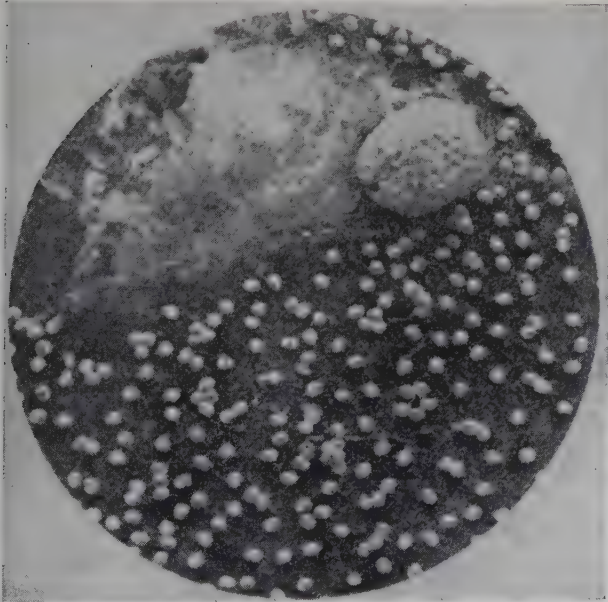


Fig. 7. Cocoon and eggs of the garden spider (*Epeira diademata*)

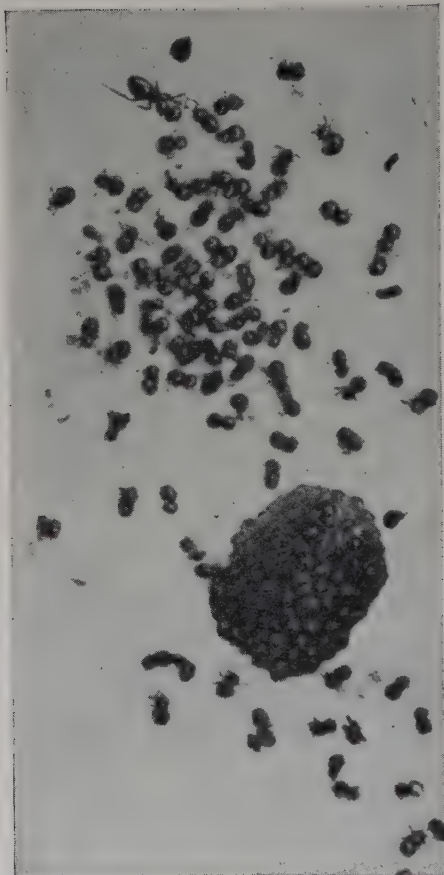


Fig. 9. Young garden spiders hatching out from the eggs of a cocoon

loid spiders and poisonous tarantula spiders of the tropics sometimes come north to this country packed in crates of fruit.

The trap-door spider digs a short, broad tube in the ground and fixes at the top a trap door of molded earth on a silk hinge. Insects visiting the top are caught and dragged in. The raft spider, which lives on the borders of lakes, makes a raft of leaves and floats on it, but it can run over the surface and sometimes plunges below. The zebra spider stalks insects on a

sunny fence with catlike movements. Before leaping on its prey, it first attaches a silk thread to its jumping point to ensure a safe return.

Most spiders die in the winter, but a number of females live two or three years. As most female spiders devour their husbands almost immediately after mating, the sexes cannot be kept together when under observation.

AIR-TUBE BREATHERS

It is an interesting fact that insects, which comprise about two-thirds of the species of animals alive today, have some surviving relatives which plausibly represent ancestral forms intermediate between themselves and annelids. Insects have only three pairs of legs attached to the middle one of the three main divisions of the "insected" body (to coin a word meaning "cut-into"). These three parts are head, thorax, and abdomen. The thorax has all the three pairs of legs, which correspond to three body segments.

In an adult insect, such as a housefly or butterfly, the thorax, being in the middle of the length of the body and having legs, has no difficulty in supporting and balancing a good-sized head in front and a larger abdomen behind. But in a caterpillar, which is an immature butterfly, the abdomen is of immense size. It doesn't balance the head at all, but trails along behind the thorax supported by temporary legs, called pro-legs or false feet, one pair per segment, for as far as they go. On the face of it, the caterpillar looks more like a worm (a series of segments all much alike) than like a real insect, "insected" into its three very different parts.

The suggested similarity between insects (especially when young) and

annelids has something to be said for it. Consider for a moment the myriapods, e.g. centipede, the nearest air-breathing relatives of insects. They, like a caterpillar, consist of a string of similar segments as in annelids. In fact, they would be justified in claiming to be an evolutionary link between that primitive group and insects. Before considering them further, however, we should first make the acquaintance of *Peripatus*.

This rather rare, tropical, wormlike arthropod, found in both hemispheres in moist places under fallen leaves and logs, is still more closely related to the annelids. It has a velvety green, or chocolate-colored skin, very soft and wormlike in that respect. Its legs are thick and stumpy, not jointed like those of myriapods and insects. Its jaws and pairs of kidney tubes are also like annelids (marine annelids have jaws). Its two separate nerve cords, which form a ring, hark back even to the primitive flatworms. On the other hand, its breathing tubes and circulatory system are like myriapods, and it is regarded by zoologists as a very primitive arthropod.

Next to it in structure come the *centipedes*, which are often classed for convenience with millipedes as myriapods though the two are very different. Centipedes are flesh eaters, and have fewer legs than the vegetarian millipedes, but it must not be inferred that "hundred feet" and "thousand feet" implied by their Latin names are to be taken literally. Our most common centipede has only 15 pairs of legs, and one pair of poison fangs taking the place of legs on the segment close to the head. It has a pair of spiracles on the sides of each segment, leading into breathing tubes.

Millipedes are never flat like centipedes, but are almost cylindrical. Except up in front, every segment of the back covers two pairs of the numerous legs. Their mouth organs (a pair of jaws working sidewise and a pair used as an under lip) are simpler than those of chewing insects but much like them. They eat fallen fruit and any sort of decaying vegetation.



Fig. 10. The water spider in its nest

INSECTS

Insects, or, as they are often called, "hexapods," meaning "six-footed," are so diversified that to keep track of them at all, they have to be grouped in orders, of which some two dozen are now commonly recognized by entomologists, though we shall have space for only a dozen or so. Their



U.S. Department of Agriculture

Fig. 11. This species of the American cockroach, *Periplaneta americana*, is a flying species especially troublesome on ships

names almost all end in "-ptera" which is Greek for "wing."

The two lowest in the scale, i.e., most like the myriapods and *Peripatus*, are, however, wingless, and

most of them are extremely small and retiring. They are found in moist and usually dark places. One of them, called the "silver-fish," an example of the bristletail order, is nearly one-third of an inch long and often seen in basements and cupboards. It is shiny white, with a pair of long feelers (antennae) on its head and three long sensory bristles on its tail. It darts about somewhat like a fish, as to speed; its silvery surface is covered with microscopic white scales.

ORTHOPTERA: The name of the order Orthoptera, "straight" wing, refers to the straight and narrow front wings. The hind wings (insects never have more than two pairs) are wider and more delicate; they are folded together like a fan when not being used.

Cockroaches, while excellent runners, as anyone knows who has tried to catch one, are famous fliers. In the tropics, one has only to sit in an un-screened, lighted room at night to be visited by a great variety of interesting species. Some are of a delicate green, but brown is the prevailing color among the 1,000 or so known species. The Oriental roach, sometimes improperly called the black beetle, is a great traveler; as a stow-away in the warm holds of vessels it has visited practically every port. It is, by the way, neither black nor a beetle. Sugar refineries and wharves are among its favorite resorts. Its female is practically wingless. The croton bug, *Blattella germanica*, a smaller species, reached these shores from Europe and is our most common domestic cockroach, but there are several wild species, even in the northern states, in the woods under rotting bark. Cockroach eggs after

fertilization are carried in a long, cylindrical capsule attached to the end of the body of the female.

Grasshoppers, the next group among the Orthoptera to be considered, are even more of a problem than cockroaches, but to avoid any false accusations we must first separate the sheep from the goats, so to speak. Two different families go by the name of grasshopper in popular speech, but entomologists prefer to apply that name only to the "long-horned," green tribe, such as the katydid and meadow grasshoppers, none of which are common enough to be pests, and to call the "short-horned," brownish ones, some of which travel over the land in immense devastating swarms, "locusts" or Locustidae.

Of course it is not proper to speak of long and short "horns," for the delicate, jointed, thread-shaped antennae on the forehead of a green grasshopper such as the katydid are feelers, organs of touch and probably of smell, but nicknames are often very convenient.

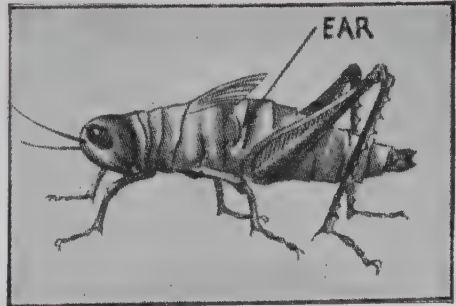
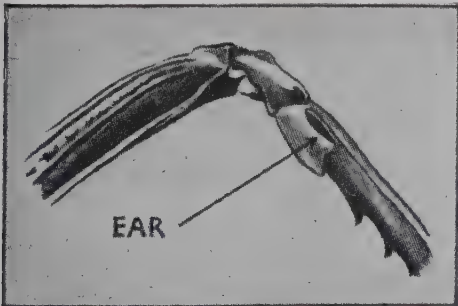
Katydids, as is well known, get their name from the constantly repeated, strident song made at night by lifting and rubbing together the front pair of wings. The male (as in crickets) has a filelike cross vein at



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Fig. 14. The European saga grasshopper is closely related to our American katydid. The long ovipositor with which it deposits its eggs in the ground is not a hollow tube, but is composed of closely-joined sections which part to make way for the egg

the base of one wing which plays upon a corresponding furrow in the other and produces the rasping voice. The wife, Katy, says little, but may be recognized by the sword-shaped, upward-bent ovipositor. The eggs are laid on twigs and leaves of trees among which they live and sing and mate. The probable organ of hearing in the green grasshopper is beneath an oval drum which is easily seen on the foreleg (tibia, just below the "knee"). Locusts make sounds by rubbing their hind legs over their furled



Figs. 12 & 13. Ears of long-horned (Fig. 12, left) and short-horned (Fig. 13, right) grasshoppers

front wings; they hear through drums, one on each side of the first segment of the abdomen (Figs. 12 and 13).

The migratory Rocky Mountain locust is the species which in some years is a veritable plague, the old ones flying in dense swarms; the young, before their wings have grown, marching in armies, devouring every scrap of vegetation, fording streams by leaping over one another in dense masses. The eggs are laid in holes drilled into the surface of the ground by the end of the abdomen of the female. The common black cricket, the female of which has a long, straight egg depositor, lays her eggs in the ground in a similar way.

Some of our common green grasshoppers seen sidewise look much like leaves. In the South American



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Fig. 16. The praying mantis assumes his worshipful position not in order to pray but to capture the smaller insects upon which he feeds



Anders & Co.

Fig. 15. On the under side of the praying mantis are two bright spots with which he lures the insects that are his prey

tropics and in Central America there are numerous leaf-mimicking grasshoppers, with forewings which are not only green and shaped like an oval, pointed leaf, but with veins much more like those of a leaf than most other insects. In certain genera and species closely related to them, the forewings are brown and yellow, resembling dead or dying leaves; dark chestnut, pale and washed-out; reddish-purple, almost carmine; or red-brown. On many there are spots which look like an attack of fungus. Are all these resemblances useful, so that we can explain them as having been produced by natural selection? This is a problem needing much further study. These tree-living grasshoppers are nocturnal; we know little about their habits nor about the behavior of the birds and lizards which prey upon them. Also we are ignorant of the processes of growth, the chemistry and physiology of these marvel-

ous and still inexplicable mysteries of the insect world.

Another group of Orthoptera allied to the grasshoppers are the stick insects and leaf insects which make up the phasmids (meaning phantoms, specters). The leaf insects of this group are flat, not on each side like green grasshoppers, but above and below.

The stick insects are faithful imitations of sticks, and their sluggish habits and tendency to "freeze," or stand rigidly when touched, assist in the deception, which certainly is effective in preventing attacks by insect-eating foes. Many species, of all dimensions up to a foot long, are found in the tropics. In our middle states there is a common species found usually on the oak. The female, larger than the male, casts her well-protected, ovoid eggs carelessly upon the ground. Reproduction by parthenogenesis is very common. Males are rare and are almost never produced in some species. Only short, stumpy, useless wings are the rule.

The sanctimonious praying mantis is almost as lanky as a stick insect. It has wings when mature, and is a busy hunter and fly catcher. Its spiny forelegs are excellent fly traps; being long and doubled together at the joints as if the insect were resting on bended knees, the mantis has acquired the name "praying." This attitude is a sham; as soon as a fly, or other juicy insect, appears, those legs are shot forward about the luckless prey, and drawn back with it to the mouth. They are especially active at night. The eggs are laid in capsules glued upon twigs of trees. The male is common but smaller and weaker than the female, who often attacks and eats her husband.

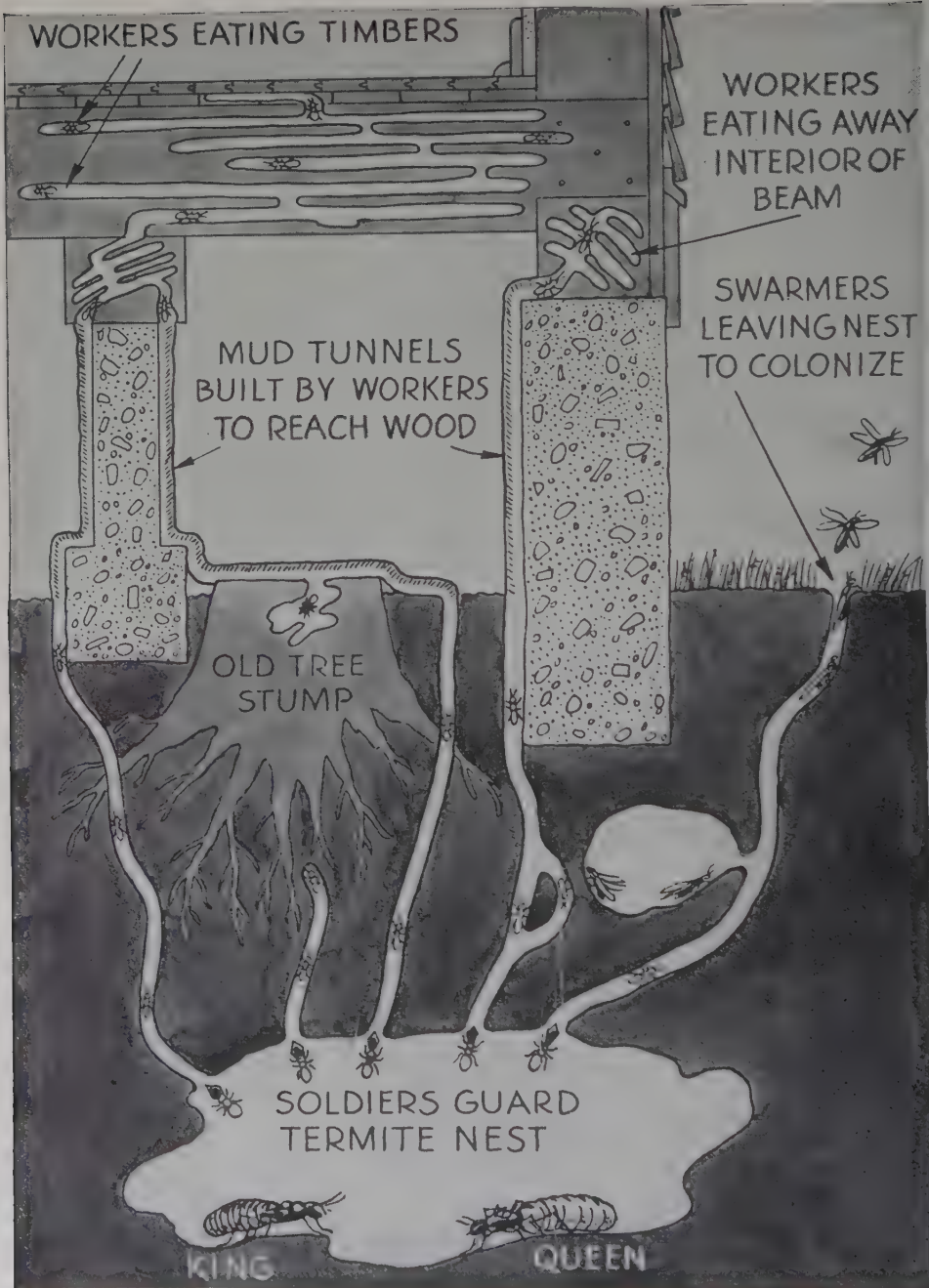
ISOPTERA: Termites are much more primitive in structure than ants. Their wings (when they have any) are all four of them alike or, as the zoologists say, are undifferentiated. They grow up without any resting stage, like Orthoptera, unlike ants. They have no slender waist like an ant.



American Museum of Natural History

Fig. 17. This Tropical American termite nest is made from masticated woody material

Since they seldom venture out into the light, they are white. Their homes, or rather communal apartments, are excavations which they have gnawed out of wood, or enormous "hills" which some tropical species construct. Everywhere in the tropics they are a pest, invading houses, and reducing table legs and woodwork to mere shells which fall to pieces when any pressure is put on them.



Popular Science Magazine

Fig. 18. Diagrammatic representation of a termite colony

A community is made up of several castes or kinds of individuals (Fig. 18): (1) the queen and king, the only winged members, and sexually mature. After a marriage flight, the queen sheds her wings and devotes herself to egg-laying. Her abdomen becomes an enormous sac, without much change in the size of her diminutive head and thorax. In an African termitary, the queen often has an abdomen two inches long and an egg-laying capacity of 60,000 eggs per day; (2) reserve queen and king, sexually mature but wingless, and not taking part in reproduction except in an emergency; (3) sterile workers, wingless and usually blind; (4) soldiers, on police duty, with formidable jaws and big muscular heads. Unlike ants, the sexes appear to be equally represented, in spite of the sterility of workers and soldiers.

MAY FLIES AND STONE FLIES:

In any small pond or stream one can find in summer a wealth of insect life, which may be profitably studied at home in an aquarium stocked with water plants.

Among the insects which one will find climbing over stones at the bottom, are the young, or nymphs of may flies and stone flies. Their wings have not yet grown, and they have plume-shaped extensions of their breathing tubes, called tracheal gills, projecting into the water. They are representatives of two large orders of water insects which never pass through a resting stage (pupa or chrysalis), as do the members of the "higher" orders, the bees, flies, and beetles. May flies and stone flies are, like Orthoptera, active all their lives, but the winged, aerial adult is so different from the debutante nymph

that it is said to have a "metamorphosis" (change of form), though it is incomplete. Complete metamorphosis of higher insects, on the other hand (larva→pupa→adult, or imago), includes a period of motionless inactivity, a long sleep.

May fly nymphs are usually smaller than the stone flies and can be distinguished by their feather-shaped gills on each side of the abdomen, rather than on or under the thorax, as in most stone fly nymphs. They have three tail appendages (either feelers or gills) rather than two, and only one claw instead of two.

The adult may flies hold their wings upright and their hind wings are small and flat; stone flies at rest fold their wings over their back, and the hind wings are large. May flies are also called dayflies or Ephemerae, ephemeral in that the adult life is short, though not limited to one day. They are the only insect known to molt, or throw off the entire skin, after reaching the adult stage.

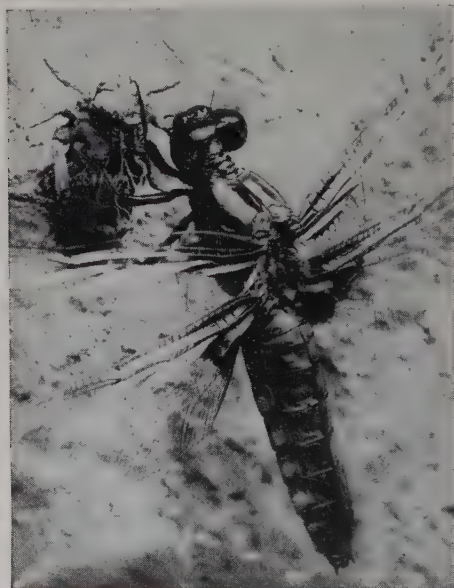
They swarm over trout streams and are imitated as the "artificial flies" used by descendants of Isaac Walton everywhere. Stone flies, retiring in their habits, are seldom seen in large swarms like those of may flies about electric lights. Some of them seem insensible to cold and are found wandering over snowbanks in early spring.

DRAGONFLIES AND DAMSEL

FLIES: Common in every pond and stream are the nymphs of the large dragonflies and their more delicate and somewhat different relatives, the damsel flies. Both are carnivorous and have such large jaws that the order to which they belong is named from its "teeth," Odonata (odon is Greek

for tooth), rather than for its membranous wings.

To tell an adult damsel fly from the more sturdy dragonfly, you have only to notice that "she" modestly furls her wings over her back when at rest, while "he" spreads them out



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Fig. 19. This flat-bellied dragonfly has only recently emerged from the comparatively small larva skin in the top left-hand corner, in which the dragonfly has lived until now

horizontally. "She," you will understand, is of either sex, and so is "he."

The nymphs are easily told apart, not only by the slender as opposed to the thick and bulky form, but also by the fact that "she" has three leaf-like gills extending backward from the end of her abdomen, while "he" draws or pumps water into the end of the alimentary tube (breathes through his tail). There, in a chamber the pleated walls of which are full of air tubes, diffusion of gases takes

place; oxygen is extracted from the water, carbon dioxide is passed into it. Then the nymph shoots out the used water and takes another breath.

The nymphs have an innocent-looking mouthpiece for catching insects. It folds back under the head, and the end of it looks more like a spoon than a pair of pincers, but once a small insect comes along, the jointed apparatus unfolds, is thrust forward, the sharp nippers spread open, and the prey is seized and drawn back up into the mouth between the real jaws. All this is done by what is actually a mechanized underlip.

The nymph, when ready to become a "fly" or "darning needle," climbs the stem of a water plant. The skin of its back splits open, and out of it creeps the adult, which waits until its soft, flabby wings fill with blood, spread out, and become dry. Then it takes flight and hawks around the pond, catching mosquitoes.

TRUE BUGS, HEMIPTERA: Tubular beaks used in sucking blood or the juices of plants are as characteristic of true bugs as are "half" wings. This means simply that the half of the fore wings attached to the body (middle segment of the thorax) is leathery and tough, while the rest of the wing is membranous like the hind wings.

Blood-sucking bugs are found in every little pond, where they swim about from the time they are hatched until their wings are grown, and even then they are not likely to leave the pond until it dries up and leaves them high and dry. Then they migrate to other ponds, and some of them may be seen at night beating around electric lights.

One group of the Hemiptera can be identified by the peculiar disagree-

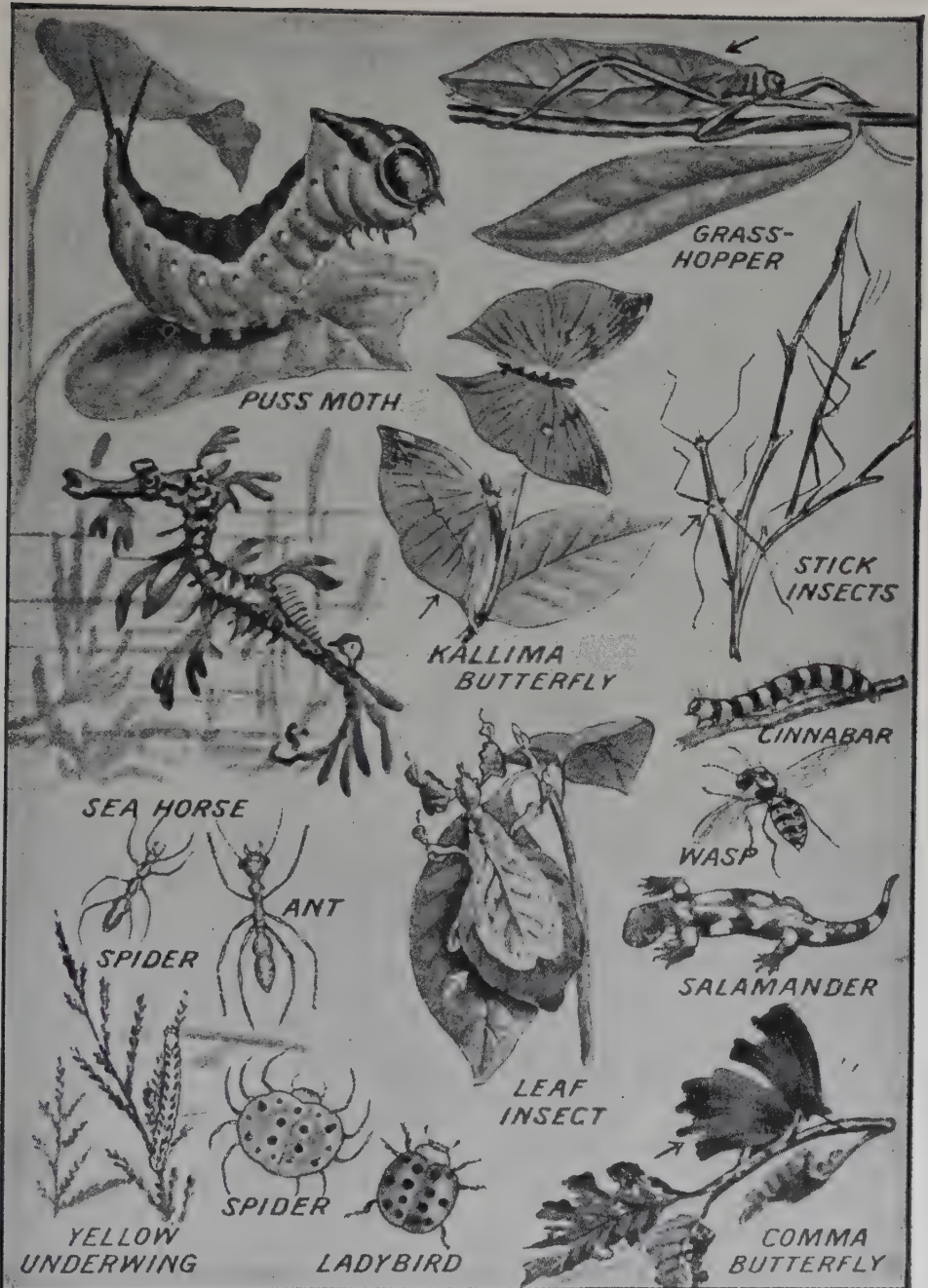


Fig. 20. Some extraordinary examples of self-preservation in nature by camouflage and protective imitation

able odor which it emits. Bugs of this group are called—plainly and succinctly—stink bugs.

The biggest and most conspicuous are the giant water bugs, an inch and a half long and powerful enough to attack and feed upon newts and young fishes. Their front legs have a terminal hook, and shut together like a knife blade, so they are as well adapted for grasping as their flat, hairy, oarlike legs are for paddling.

Much more common than these giants are the little water boatmen, less than one-half inch long. They carry about them, as they dive, a cushion of air, and anchor themselves at the bottom by hooks on their long middle pair of legs and suck the juices of algae and mosquito larvae.

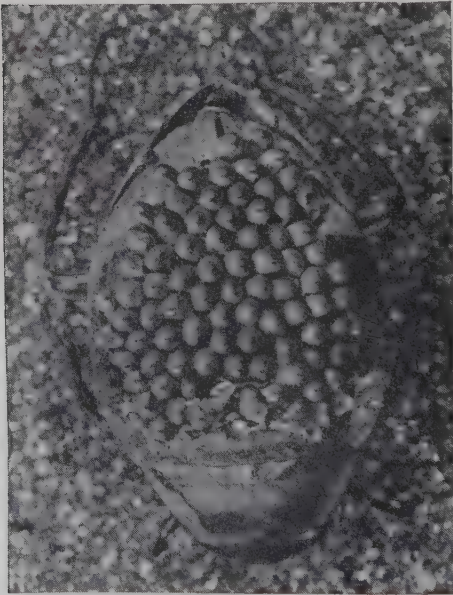
Only a little larger are the backswimmers. Their backs are arched al-

most like a keel, white, and turned toward the bottom as they swim with their long, oar-shaped legs. They come to the surface for air, which is stored in a film along the back, held by fringes of hair. These lively fighters do not hesitate to thrust their beaks into all comers. Hence caution is necessary when you pick them up with your fingers.

On the surface of still water the water spiders skip about, often in rather large groups. Their lanky legs have microscopic bunches of hairs at the tips of their toes, enclosing air, so that their feet never get wet. Often they are wingless, even when full grown. They are slender and delicate, but able to catch and suck tiny insects. Little can be said for the terrestrial relatives of these water bugs. They are among the most unpleasant of all insects; offensive, many of them are, to our sense of smell; others lie in wait for the blood of human victims.

Of them all, the bedbugs are the most notorious. Lurking in crevices in woodwork, they steal forth at night to drink their fill of blood. Man is not the only victim, for they are fond of birds and bats. Spots of ill-smelling, brown secretion show where they have been. Their very flat, almost circular, brown abdomens are not covered by wings, and they cannot fly. They are only one-fifth inch long, but in Central and South America, huge assassin bugs an inch long are frequent. Some of them called "kissing bugs" are venomous and, in Brazil, are known to transmit a protozoon causing a sort of sleeping sickness.

Some of these predaceous bugs help in assassinating insects, but their services are not highly regarded. Many, such as the squash bugs, leaf bugs,



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Fig. 21. The male water bug, *Diplonychus*. It carries the eggs its wife lays on its back until the young emerge

cotton stainers, clinch bugs, and multitudes of others, make life hard for the farmer.

HOMOPTERA: Aided by the entomologists, the "true bugs" have become more and more exclusive. Not long ago they included in their ranks the Homoptera, which have now seceded on the strength of the fact that, when they have wings at all, those in front are normal membranous affairs of full size, not just half membranous as in the Hemiptera. All of them are sap-suckers, with beaks made up of drills and sucking-tube.

The larger Homoptera are much less objectionable to the farmer and gardener than the smaller (aphids, scale insects, and white flies). The latter, with their beaks stubbornly stuck into leaves and a reproductive activity probably nowhere excelled in the animal kingdom, are unmitigated pests.

The larger Homoptera are best represented by the Cicadas. Two of these are well known in the eastern United States: the harvest fly or dog-day locust, and the "17-year locust." "Locust" as applied to these insects is an unfortunate Americanism, for they are not locusts at all. In southern France cicadas are the cigale, made famous by the works of Fabre, and even the Latin poets were impressed by the fact that cicadas, notorious singers, had "voiceless wives."

The shrill, sawmill-like song of the northern harvest fly is familiar to every Yankee. Beginning with the dog days of early August or the middle of July, the sonorous buzz of the males seems to issue from every tree. The voice comes from a pair of large, elliptical membranes, stretching like drum-heads across the underside of the

body, just back of the hind legs and over the front part of the abdomen. Each drum (elastic convex membrane) is stretched taut by a muscle attached to its middle. A crackle results when the muscle relaxes. Rapidly repeated changes in the tension of the muscle



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Fig. 22. The harvest fly. His singing has probably kept you awake some summer night

throw the drum into tremendous vibration, which may extend over the whole body. These rhythmic contractions continue for a considerable period after the song has been interrupted. As there are over 127 species of harvest flies north of Mexico, great variations in the song are to be expected; 34 or more of West Coast species alone have been recorded.

One large species (*Quesada gigas*) distributed through the tropics from Texas to Argentina has a shrill cry like the whistle of a locomotive and audible a long distance. Scientists have described another large species in the forest of Borneo, which shrieks not unlike the braying of an ass in high treble.



Anders & Co.

Fig. 23. Natural selection has evolved this well-camouflaged tree hopper

The harvest flies are remarkable for their long period of development underground as wingless grubs or nymphs. This may be only two or three years, although the "17-year locust" lives underground, feeding upon roots for 17 years. In any given region, the adults make their appearance at 17-year intervals. This species is easily recognized by its red eyes and yellowish wings.

Quite as interesting in their way as the cicadas, are the little tree hoppers, many of which are excellent imitations of small thorns on the trees or vines which they inhabit. By poking them not too carefully, they jump, but seen at rest and feeding, as they usually are, they are likely to be mistaken for thorns or other excrescences, often of grotesque figures and shapes, depending upon the species being examined. These peculiar growths involve the extraordinary overdevelopment of the front segment of the thorax, which in most insects is a small, flat plate; in these hoppers it grows upward and backward over the body and wings.

Seen away from their natural habitats, it is not easy to understand how some of these grotesque growths can be useful to the tree hopper. They look like absolute freaks of nature, due to their mysterious growth tendencies of which we know nothing. To see whether they are useful and have been favored by natural selection during the past ages of their evolution—that is, protected from the onslaughts of birds, reptiles, and other insect-eaters—one would have to study each species on its native food plant. This would be a fascinating study.

Spittle insects, or froghoppers, are also small bugs about one-quarter inch long, trim in appearance, with a broad head and projecting forehead. The interesting thing about them is that they manufacture out of sap a frothy mass in which they and their nymphs live and grow to maturity. Such froths are often seen on grasses in early summer.

The plant lice, or aphids, of many kinds are the most omnipresent pests of everyone who grows plants indoors.



U.S. Department of Agriculture

Fig. 24. Another well-camouflaged tree hopper, *Entylia sinuata*. The tree hoppers frequently are sap-suckers, hence are injurious to the trees on which they live

In the field and garden, too, they are a menace, but less well-protected against weather and insect foes. Once they get established on a shrub, tree, or plant of any kind, they hold their own against all comers. Poisons sprayed upon them are without effect, for they do not chew and swallow poisoned leaves but, with beaks plunged deeply into the harmless sap, they drink on as if nothing had happened. The only way to kill them is to fill their breathing-pores and tubes with a sticky oil-emulsion or other concoction which will smother them, or rather, some of them, for they are very resistant and reproduce endlessly and prolifically.



Fig. 25. Aphid, or "green fly," sucking the juice from a young rose shoot



N.Y. Zoological Society

Fig. 26. Woolly aphids, once they attack a shrub or tree, are among the most difficult pests to eradicate

During the greater part of any summer, or season of activity, only wingless females are to be found, surrounded by young ones of all ages which have been born "alive" and without a father; in other words, viviparously and parthenogenetically. They do not, at this time of the year, mate nor lay eggs; the eggs within the mother's ovaries develop without fertilization until they have become young female nymphs ready to be born and settle down under the leaf beside their mother. Later in the season females with wings are born, much like their mothers but reaching a more advanced stage in development. These are "migrants." As the food gets poor and conditions crowded, they spread their wings and are off to better feeding grounds. There are as yet no males around, but they can reproduce without them. By

now the food is tougher and less juicy. It is August or September; cool nights and less daylight slow up plant growth, and their own internal workings are changed. They begin to produce males, as well as females, both with wings.

Now, usually late in autumn, family life is established on a normal basis. Parthenogenesis is done away with. Eggs are fertilized as in most

Scale insects are likewise mostly females, wingless, eyeless, and even legless, degenerates. About all that they have left is their sucking beak and parthenogenetic ovaries. But they construct their own little house out of a hard, waxy material which they secrete, building it above and then round and round themselves in layers, as a dome-shaped shell. It comes from their tail ends, and they may either waltz around to construct a circular igloo, or the house may be elongated, as in the oyster-shell scale found on nearly every apple tree.

Beneath this shanty the young are born, which must have some very slight powers of locomotion, for not far from home one is sure to find minute scales where nymphs are setting up housekeeping on their own. In some species, males are unknown. When they do appear, they have six good legs, but either no wings at all or only a single pair. Their life is bound to be short, for usually they have no beaks for sap-sucking and never the power to construct a scale-like shell.

Their relatives, the mealy bugs, are covered with a white powder, which they secrete, or have long threads of the same secretion around the margin of the body. A similar secretion is still more prominent in the woolly aphids of the apple or of the alder. Such masses of this white, woolly, waxy secretion cover the clusters of aphids that the insects are completely concealed from view. This ability to secrete wax in Chinese and East Indian species has been put to a commercial use. Lac comes from the scales of another species, composed mostly of a resinous gum mixed with wax. Various dyes come from the bodies of these insects: lake, a red



U.S. Department of Agriculture

Fig. 27. These citrus mealy bugs, close relatives of the aphids, secrete a white powder which is harmful to fruit trees

insects; they are usually tiny, black, shiny eggs, often seen on the tips of twigs in fall and winter, protected by a tough shell from the elements. The strange thing about them is that in the spring, they all hatch into parthenogenetic females which start the ball rolling again, raising happy families, all girls for several generations. It is needless to say that this happiness is not shared by the horticulturalist who considers them pests.

dye from the lac insect; cochineal in crude form, the basis of carmine.

Aphids and some scale insects secrete honeydew, a sweet, sticky fluid, highly prized by the ants. When you see ants parading over shrubs, you will be sure to find aphids, which have often been called ants' cows. Gently stroked by the antennae (feelers) of the ants, the cow pours out from the two tubes above its tail droplets of this precious syrup.

DIPTERA: The true flies, or *Diptera*, such as the housefly and mosquito, have but two wings (Fig. 28). The second pair has been replaced by two tiny knoblike balancing organs, or "halteres." If one of these halteres is removed, the fly loses its balance. They serve the same purpose as the little balancing channels in our ears by which we feel giddy when we have twirled round too much and their contents are disturbed.

How does a fly walk upside down on the ceiling? If we examine its feet under the microscope, we see that there are little hairy cushions. Microscopic tubular hairs emit a sticky excretion that makes it possible for the fly to walk up a window pane or to hang head downward from any object. If we put the tip of a fly's tongue under a

powerful microscope, we see still another cushion pad. When a fly feeds, it lowers its curious tongue on to the food. Actually, it secretes a slime that partially dissolves the food, thus allowing it to be sucked back through the grooves of the tongue.

"Where do flies go in winter time?" is a popular question in regard to our common houseflies. There is no mystery as to their whereabouts for those that survive the frosts hibernate in warm crevices, and emerge in spring.

The housefly, the bluebottle, and other carrion flies, serve a useful pur-



Fig. 28. A female mosquito (*Culex pipiens*). Only the females bite



Fig. 29. The common housefly. Flies have two pairs of wings and compound eyes, composed of a mosaic of lenses. Notice the hairs that carry the disease germs

pose as scavengers, laying their eggs in offal, waste, and decaying meat, which their grubs eventually eat.

A housefly lays over a hundred eggs in a batch, preferably on manure or garbage. They are long, shiny, white ellipsoids, one-sixth inch in length. In midsummer they hatch about eight hours after they are laid, and ten days or a fortnight is long enough to complete their entire development. The young are lively, white, cylindrical maggots, tapering to a point in front, blunt behind. They breathe through two pairs of holes (spiracles), one pair just back of the head, one on the upper part of the blunt hind end; running forward and back and connecting the spiracles are two long, shiny breathing tubes with branches in each segment.

The maggot (larva) grows fast, molts twice, and in about a week becomes a pupa, or resting stage (the word meant "doll" to the Romans). This is an oval, dark chestnut affair about one-quarter inch long, enclosed

in a tough shell. It lives on its fat, stored up during its busy, gormandizing, larval stage, and now takes no food. After a sleep of three or four days, a little circular lid at the head end of its shell is pushed open, and out walks the mature fly.

It has undergone what is called a complete metamorphosis (form change) between egg and adult. During the resting stage, its wings, legs, big compound eyes, and all the set-up of a sexually mature fly

were developed. It is now ready to mate and, if female, to go about the important business of egg-laying. Feeding is now quite incidental; it must drink, and it sips whatever sweet and savory dishes you leave uncovered, but it never grows, or molts. The female, especially, visits all sorts of places, and the male usually goes with her. It is no wonder that the housefly has been proved to be a dangerous carrier of the germ (bacillus) of typhoid fever.

Because of another of the Diptera, the mosquito, Ferdinand de Lesseps, the engineer of the Suez Canal, was forced, after thousands of men had died of malaria, to give up his attempt to drive a canal through the Isthmus of Panama. Little was known of malaria, or how it was carried, when de Lesseps made his ill-fated attempt. It was not until Dr. Philip Manson-Bahr and Sir Donald Ross had completed a careful study of the disease and traced the life history of the protozoon germ within the mosquito,

that the construction of the Panama Canal became possible.

When the Americans took over the derelict works of the French enterprise, they first set about exterminating the mosquitoes. They poured oil on the pools, in which the larvae spent the first part of their lives as aquatic wrigglers, so that these air-breathing larvae were suffocated by the oil on the surface.

It was subsequently discovered that another mosquito carries the germ of yellow fever. In Africa, the blood-sucking tsetse flies were found to carry the trypanosome, or protozoon germ, of sleeping sickness.

The common mosquito, *Culex pipiens*, does not carry the germs of malaria. The carriers belong to the genus *Anopheles*. These may be distinguished by the fact that they hold their bodies in a straight line when at rest, *Culex* having a humped-back appearance.

It is only the female mosquitoes that do the "biting." Males may be recognized by their large plumelike antennae; the one shown in the figure is a female; her antennae are slender. Before laying, the female regularly takes a full meal of blood from some warm-blooded animal, which often means man but may be whatever mammal or bird is unfortunate enough to be within reach. *Culex* lays her eggs on the surface of stagnant water in swamps or in old tin cans behind the house. They are long, oval, and fastened together in a bunch shaped like a shallow boat or raft. *Anopheles* lays hers singly on the surface.

The larvae of *Culex* are called "wrigglers" from their snappy way of swimming, bending, and suddenly straightening. They come to the sur-

face to breathe by extending the breathing tube at their tail end up into the air and then hanging head down into the water. The *Anopheles* larva lies flat against the surface, with a very short breathing tube extending up from near the tail. This method of breathing at the surface makes it very easy to suffocate the larvae by pouring a film of crude oil or kerosene over the water.

The same applies to the hunch-back pupae of both *Culex* and *Anopheles*. Their breathing tubes, however, extend up in a pair from the thorax. The pupa rests near the surface, with breathing tubes up at the water level. Development is rapid and about as follows: egg 24 hours, larva a week or 10 days, pupa 2 days.

Related to the mosquitoes are long-legged crane flies which look like a



U.S. Department of Agriculture

Fig. 30. *Aedes aegypti*, the mosquito which transmits the yellow fever virus

greatly exaggerated mosquito but do not bite. They are sometimes referred to as daddy longlegs. While that term fits them, it is unfortunately pre-empted by the harvestmen, spiderlike creatures with eight legs which exceed those of the crane flies in length and fragility.

Crane flies usually fly slowly, except some small species which cavort or "dance" in the air in swarms like those of the midges, which are also relatives of theirs. Crane flies are found chiefly in wet meadows, where they lay their eggs at the roots of grasses, but also in shady places where decaying wood and fungi are available.

In these places, too, you find fungus gnats, one genus of which is *Sciara*, famous for the thorough investigations upon its heredity and cell-organization being carried on at Johns Hopkins University. One of its species in Africa is called *militaris*, the military sciara or African army worm. When ready to change into pupae, the larvae (maggots) leave the decomposing forest leaves on which they have fed and gather by millions into great strings or ribbons held together by their sticky secretions. These squirming masses migrate over the forest floor like serpents, and are said to be sometimes forty to a hundred feet long, five or six inches wide, and an inch in depth. Smaller processions have been seen in Europe; in the United States writhing clusters of similar species may be found under the bark of rotten trees.

Gall gnats are the most minute of all midges. One of the most common lays its eggs on a terminal leaf bud of the willow. The diminutive larvae check the growth of the stem, but new scales are formed about the base or the bud, successively larger and

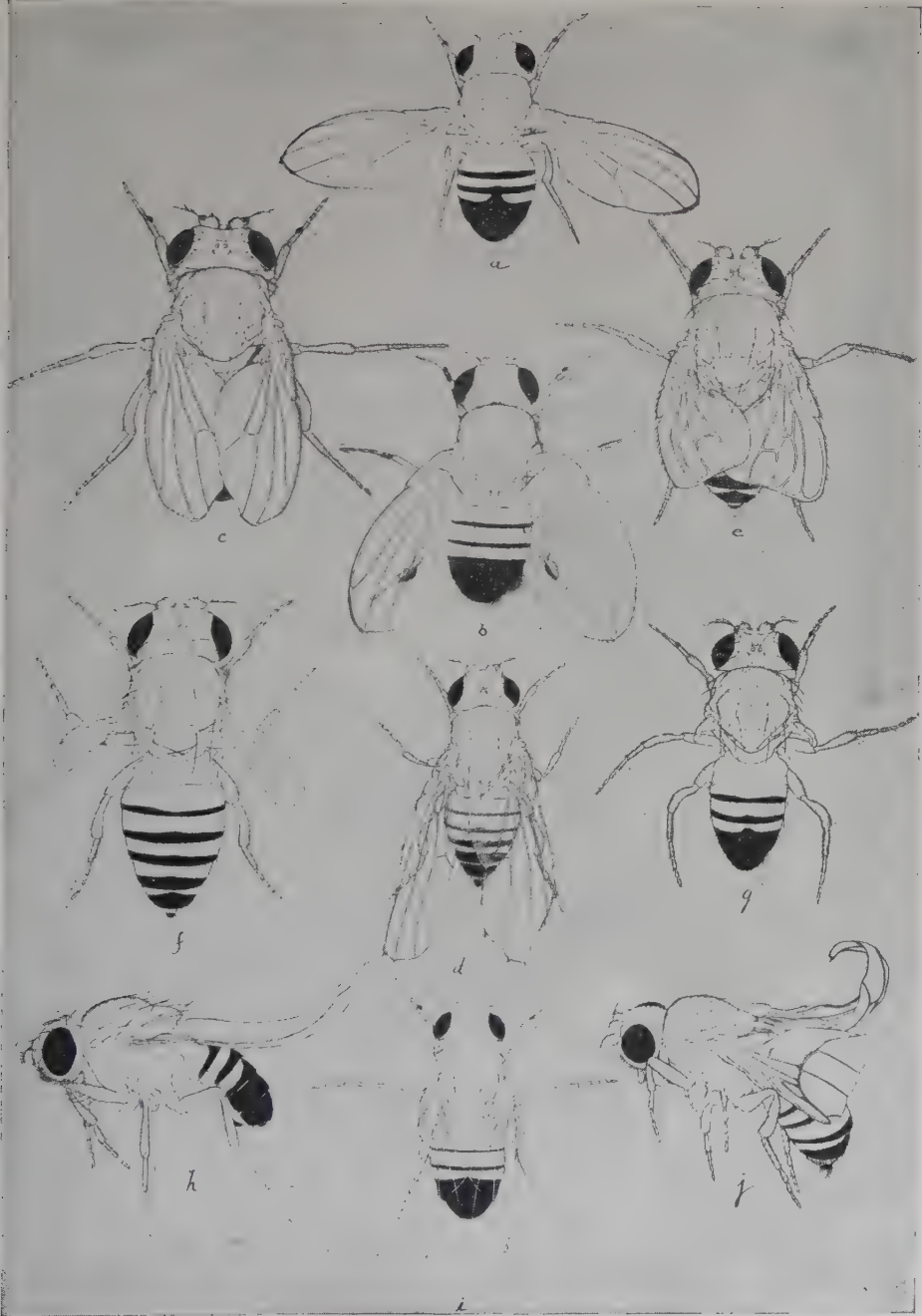
larger ones, until there seems to be a pine cone growing on a willow. These cones often may be seen on young trees growing by the roadside.

Another gall gnat is the Hessian fly, a serious scavenger of wheat in this country, said to have been introduced in infested straw by the Hessian troops during the Revolutionary War. The larvae live at the base of the leaf, between it and the main stem, so weakening it that very little seed is produced.

Galls are also formed by some of the housefly-like members of the Diptera. One of these, with dark bands across its wings, very sluggish in its movements, lays its eggs in a young golden-rod stalk, which then grows out into a spherical gall enclosing the larva. If these galls are brought into a warm place in the spring, the fat, chunky grub (larva) inside rapidly transforms into a pupa and then into the very mild-looking fly. A smaller species, much like it in appearance, may be found resting on young apples in the spring, for on these it lays its eggs just beneath the skin. The minute, developing larva burrows through the pulp, making the altogether too familiar trails of the railroad worm.

Famous for its contributions to the science of heredity is the diminutive *Drosophila*, which means in Greek "dew-lover," though it much prefers fermenting fruit, pomace of cider mills, and wine vats. It haunts the fruit stores, and thrives on slightly acid, fermenting bananas. The ease

Key to Figure 31. *a*, spread wings; *b*, bent wings; *c*, miniature wings; *d*, beaded wings; *e*, rudimentary wings; *f*, vestigial wings; *g*, apterous (wingless); *h*, ski wings; *i*, cut wings; *j*, curly wings. These drawings show the flies magnified many times by use of a compound microscope



Dr. Thomas H. Morgan

Fig. 31. Hereditary wing variations (mutations) in *Drosophila*, the pomace, or vinegar, fly. See the key opposite

with which it may be bred and the fact that a new generation may be had every fortnight led to its being adopted as a laboratory animal by Dr. Thomas H. Morgan and his associates, and to the discovery of new laws of heredity and evolution. Biologists and college students all over the world are breeding and studying it.

One of the most interesting of the numerous kinds of the larger flies are the flower flies, or hover flies (Syrphids), many of which look like bees or wasps or even bumblebees. Like wasps, some are cross-banded with yellow, on a black, blue, or green surface. They hover over flowers and feed upon the pollen and nectar. The larvae of some species feed on aphids, others (drone flies) or carrion; those that live in wet filth, or in dirty, brackish water, have a long breathing tube which they extend out into the fresh air. These are called rat-tailed larvae.

Perhaps the most curious of all Diptera is the sheep tick, a wingless fly which lives parasitically in the wool of sheep, to which it clings with sharp claws. It is not really a tick, for that name applies to a group of eight-legged relatives of the spider, from which its structural parts are very different. An interesting point about it is the fact that the female brings forth young already in the pupa stage. Some flesh flies (bluebottles) are born as tiny maggots, ready to get busy as scavengers. The sheep-tick larva, however, is nourished by a milky secretion in the mother's uterus until full grown; then the pupa is glued to the wool, till it emerges as an adult with well-developed claws.

SIPHONAPTERA: The flea, so often an object of levity, is adapted to the life of a blood-sucking, external

parasite; it has lost its wings and is flattened sidewise, so that it does not easily get brushed off its host. Its main progression is by jumping. Its record is about one foot, and if man could jump as high in proportion to his size, he would be able at one bound to clear a skyscraper.

Some seven hundred species of flea are known, and most of them have their own particular animal hosts. The human flea, *Pulex irritans* (Fig. 32), is said to occur on only one other animal besides man—the badger. The famous performing fleas of the circus are usually dog fleas. They are comparatively large and can be attached to miniature carriages, made to carry weights, etc.

Of more importance is the fact that the eggs are scattered over the floor of houses (human flea) or among the hairs of dogs and cats. The larvae are slender, wormlike, legless, with mouths—unlike those of their parents—adapted for chewing rather than for piercing and sucking, so that they are able to live on dry animal matter, otherwise known as dirt, which collects on the floor or rugs. The pupae are enclosed in a cocoon of silk well-covered with dust. The human flea is most commonly found on the Pacific Coast; the cat-dog species prevails in eastern United States.

In hot countries the chigoe fleas burrow into the flesh of their hosts. The pregnant female chigoe of South America gets her abdomen so swollen with eggs that it reaches the size of a small pea, completely enveloping her head and thorax.

COLEOPTERA: In number of species the beetle order is larger than any two other orders put together, in fact, more than a quarter of all known

species of animals are beetles. Naturally they deserve more than a passing mention.

One reason that so many have been described is that beetles are easy to collect and pin into boxes. Since they, or the most of them, have a hard coat about them, they are durable; and best of all, they take up little room. It is no wonder that they are popular with amateurs. In France, where beetle collecting is a traditional avo-

cation, it is not unusual to find the walls of homes of amateur coleopterists literally covered with cases of beetles. Mme., the lady of the house, endures all this with equanimity. She is proud of her husband's scientific achievements and may even be the leader in these pursuits.

But even more important than the collecting and naming of beetles are our personal relations with them while alive, for some of them attack man-



Fig. 32. A photomicrograph of a flea. Notice the great hind legs for jumping long distances

kind indoors and out, in homes, gardens, fields, and forests; on the other hand, some do efficient police duty in aiding our attempts to control the insect and other pests which nature has provided to keep us awake and busy.



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Fig. 33. The larva of the water-diving *Dytiscus* beetle known as a water tiger

Among the latter, none are more efficient than the carabs, named by the Greeks from their likeness to a lively kind of crab. Like all beetles, their mouth organs (mandibles and maxillae) are for chewing; and their first pair of wings (elytra, or wing covers) are hard, convex plates, which do not flap when they fly; folded up under the elytra (as in practically all beetles) are a pair of long, membranous wings which do flap in flying.

Many of them are of brilliant metallic greens, blues, or purples. None is more handsome than the European ground beetle, imported to help in getting rid of its fellow countryman, the gypsy moth, an earlier immigrant. It is one-quarter inch long and of a brilliant shiny green. A native species, *Calosoma scrutator*, differs from it in

having reddish edges on its wing covers. Another common native, *Calosoma calidum*, one inch long, has rows of golden pits on its black elytra.

It is evident that ground beetles, like all the Coleoptera, have a complete metamorphosis. Some of them shoot from their tails an acrid fluid which forms a "hot," stinging vapor and comes out with an audible pop. These "bombardier beetles" can often be found at night in the south and in the tropics, if one goes hunting with a flashlight.

Flying along the road in summer, alighting every little while, are the active, long-legged tiger beetles, blue, green, or bronze, some of them marked with white bands across the elytra. They are only one-half inch long, but make up for it by their aggressive spirit and vigor in using their sharp mandibles. Their larvae live in holes, at the mouth of which they lie in wait for their insect prey.

Dytiscus, the diver, is a flattish, streamlined beetle nearly one-half inch long, black with brown margins. Its feet are paddle-shaped, with fringes of long hairs, and it is an excellent swimmer and fearless hunter. Small fishes, and newts much larger than itself, as well as many insects, are often attacked and eaten by the beetle and by its lanky, huge-jawed larva. The adult, when it dives, carries down air under its wing covers. On the pond's surface, the twirling black whirligigs, usually in squads of several individuals, are known as *Gyrinus*. They are less than one-half inch long, shaped much like *Dytiscus*. They grab their prey with long front legs and swim, chiefly on the surface, with the two other pairs.

Several families of beetles are scavengers, for example, the water scaven-

ger, called in Latin by a much pleasanter name, *Hydrophilus*, "water-lover." It is about the size and appearance of *Dytiscus* but its feelers are club-shaped, not threadlike and, when it swims, its oarlike hind legs, on the right and left, take turns, instead of paddling both sides together as in *Dytiscus*. But, since it is a leisurely garbage hunter, it does not need the speed of the bold and bloody *Dytiscus*.

A notorious land scavenger is the burying beetle, or sexton, which digs a grave into which a deceased animal sinks. Then Mrs. Sexton lays her eggs on it, and the larvae consume the remains. The adult is rather large, three-quarters of an inch. Prominent red bands across its black back give it a sinister appearance. Its wing covers seem too short for it, but nothing like

as short as in rove beetles, i.e., mere stumps under which a pair of long, membranous wings are folded. These are mostly tiny scavengers which you might not immediately recognize as beetles. They raise the tip of their tails as if to sting, but of course they cannot.

Of similar tastes, but unfortunately directed chiefly toward stored goods, furs, woolens, and museum specimens, is the *Dermestes*, or skin beetle. Doubtless you are familiar with the buffalo bug, if not with the larder beetle. The former is about one-eighth of an inch long and nearly as wide, a small, grayish object when adult. It is covered with minute scales and marked with brick-red or yellowish blotches. The larva is the "buffalo," covered with a thick fur, and a speedy runner. The larder beetle is longer



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Fig. 34. Lady beetles, often known as ladybirds, come out upon a mountain top after hibernation. They are valuable to man as destroyers of plant lice and scale insects

(three-eighths of an inch) and ellipsoid with a pale yellow bar across the front half of its wing covers. Its miserable larva is covered with rather long and not very thick hair. When you find some of its cast-off skins, it may be concealed nearby, and one should remember there may be eggs also.

The lady beetles are like flattened hemispheres, generally red or yellow with black spots. They and their warty, spiny larvae feed on aphids and should be encouraged in every possible way. Exception must be made, however, in respect to the squash lady beetle and, especially, the Mexican bean beetle, which, unfortunately for us, are both vegetarians. The latter, recently spreading into New England, reduces bean leaves to mere skeletons. It is well named *corrupta*, *Epilachna* being its genus name.

It is an interesting, beautiful sight on warm June evenings to see myriads of flashes apparently flowing over a meadow. The torch-bearing fireflies are a rather small, long and flat, soft-bodied beetle. The light-producing organ is at the tip of the abdomen, on the under side of the body, a region permeated with fine branches of breathing tubes. Modified fat cells secrete two substances which chemically interact with oxygen from the breathing tubes to produce light. These substances do not burn out, as one might expect, but continue to go on producing intermittent light. One of them is an enzyme, called luciferase, and enzymes have a way of acting chemically without being destroyed. The wave lengths of light emitted are all visible to us though there is no sensible heat.

The flashing of males in flight stimulates females resting on the

leaves of grass to respond by flashing, and mating occurs. Both seem to have the same intensity and duration of flash, but the male apparently knows the difference and pays no attention to other males. Changes in illumination, as evening comes on, stimulate the males to fly and to flash, and rising temperature further increases the rate of flashing.

Another family, the click beetles, "snapping bugs," or *Elatér*, have representatives in tropical America which also are luminous. They have torches in front, spots on each side of the thorax and one below, at the base of the abdomen. These beetles (*Pyrophorus*) have a longer, stronger flash than our fireflies (*Photinus* and *Photuris*, lampyrids).

Click beetles are long and narrow, with a very hard coat of mail. When they get turned over on their flat backs, their legs being too short to help them turn over, they turn a somersault and come down on their feet. First bending head and tail up as far as they can, they then straighten out with such a strong snap that they spring well up into the air. The spring-joint is in the thorax between the first and second pairs of legs. Held in the hand by the abdomen, they practice the same little trick. It may help them to confound their enemies and make a safe retreat.

As larvae, the click beetles are the tough whitish "wire worms" dug up in every garden, some of them injurious to the roots of cereal crops.

Even more effectively protected by a coat of mail are the handsome, metallic wood borers which seem to be covered with fluted bronze. They are long and narrow, much like click beetles, but they are too stiff to spring and depend upon playing dead or



Anders & Co.

Fig. 35. The "tumble-bug" beetles make balls out of dung. They transport these balls to underground cells and deposit an egg with each

upon their armor, when threatened. Their larvae are flat-headed wood borers.

Another very large family of wood borers are the long-horned beetles, easily recognized by their very long antennae, which, of course, are not horns, but feelers. Their bodies are generally long and narrow, many of them adorned with bands of bright colors. Their legs are long; they are active runners and flyers. Some of them squeak by rubbing the front segment of the thorax against the middle one. The larvae are soft-bodied, whitish grubs, tapering slightly from head to tail. They have strong jaws and can easily bore into hard wood. They can be found everywhere under decaying bark.

The ancient Egyptians were so impressed by the behavior of the chunky scarab beetles that they regarded them as sacred and somehow connected with the movements of the moon, fertility, and future life. They watched the husky females (nearly

one and one-half inches long, seven-eighths of an inch wide) with their rake-shovel fore legs rolling huge balls of dung along the ground to find a suitable spot in which to sink it into an excavation. Here, shaded from the hot sun, the female spends the summer, according to the French entomologist, Fabre, resting, and feeding on her precious ball of food.

In the autumn, she digs a larger excavation, provisions it with a ball the size of an apple, carefully prepares a small mess of nutritious predigested food with which she buries an egg. She then rests from her labors and watches to see that things go right with her offspring, a chunky white larva.

Our various species allied to the Egyptian scarab similarly deposit a single egg in a rounded mass of fertilizer.

There are well over 20,000 species of scarabs. They can be easily recognized by their rounded, thickset form and by the booklike sensory plates at

the tip of each antenna. Some of them are like the tumblebugs just mentioned, with brilliantly lustrous metallic colors. Others are not scavengers, but leaf eaters, such as our common May beetles ("June bugs" or dor-beetles). The common May beetles are not long-lived in the adult stage, but the larvae are the white grubs found in every garden, a pest which gnaws the roots of strawberry plants and lawn grass; this stage is said to last two years and sometimes even longer.



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Fig. 36. One of the scarabs, this rhinoceros beetle is here shown approximately one and a half times its natural size

The little rose bug is a slender, yellow member of the same family, which does most of its depredations in the adult-beetle stage. Buds and blossoms of the rose are its favorite food, but there is not much left of the leaves as soon as a flock of them appears in early summer.

The goldsmith beetle is a handsome, lemon-yellow representative, a little less than an inch long. It seldom is seen in large numbers. Although not useful, it is rather ornamental.

The most curious of all is the rhinoceros beetle of our southern states, which not only has a long horn

projecting forward from its nose, as a rhinoceros should, but, projecting out toward the tip of this horn, is another, formed by an outgrowth from the thorax. The two points coming almost together give the creature, which is really harmless, a ferocious appearance. The gentle female has only a little knob on her head. This species is only one and one-half inches long, greenish-gray, with black spots on its back.

Much more impressive is the hercules beetle of the West Indies, a mammoth kind of rhinoceros beetle six inches long. In spite of its size, it is of mild disposition. The larvae of these two beetles feed on rotten wood. If they were flesh eaters, their dispositions would be, presumably, better suited to their formidable outward appearance.

Closely allied to the scarabs are the stag beetles which are famous for the extraordinary development of the jaws (mandibles) in the male, which in some tropical species are as long as the rest of the body. Whether they are useful no one seems to know, nor do we know why they grow that way. Males are larger than the females and extremely variable in size and in the development of the antler-shaped jaws.

Both adult beetles and their grubs (larvae) live on decaying trees. The larvae bore into the solid wood of hardwood trees and chew it up into "sawdust." It is said that the adults feed on this prepared food and spend much of their time under dead bark. At night they fly around, attracted by electric lights, and, like June bugs, bump against the window. Development of the larva is slow, and in the common European species, is said to take four years.

The horned passalus, a curious relative of similar habits, has only moderate mandibles but tends to grow a spike in the middle of its forehead. Its name, which is Greek, means "spike." The most curious thing about it is that the larvae, under decayed bark, have stumpy hind legs used for making a sound by scraping against the basal segment of the leg in front. Why they should need to make a sound is not evident, but, of course, their point of view is different from ours.

The leaf beetles are small, usually bright-colored, leaf-eaters, varying in size, from that of the minute, jumping flea beetles which inhabit tomato plants early in the season (one-fifteenth of an inch long), to the size of the Colorado potato beetle (one-third inch), or perhaps a little larger. The larvae either feed on leaves along with the adults (potato beetle) or on roots, such as the grape rootworm. The elm leaf beetle and Japanese beetle are among the worst pests of the northeastern states.

Finally we must at least mention the enormous family of weevils, which differ from all other beetles in having a long snout, at the tip of which are minute jaws adapted for drilling holes. With this apparatus, the female bores through the shells of nuts, to lay her eggs, or into almost any kind of fruit.

The plum weevil makes a V-shaped incision in plums, apples, pears, peaches, and cherries, and deposits an egg. The fruit drops; in it a footless grub (larva) which matures rapidly and escapes within a few days to form a pupa in the ground. About 10 days later, a quarter-inch, brownish, spotted, gray-and-black weevil emerges, feeds on ripening fruit (making apples gnarled and lumpy), and passes the

winter under rubbish. Other serious and similar pests are the cotton boll weevil, grain and rice weevils, and the sugar-cane root borer.

LEPIDOPTERA: For beautiful colors and graceful flight the butterflies and moths have a prestige far ahead of that of other orders.

They are as a rule rugged individualists rather than communistic colonizers like bees and wasps (Hymenoptera) or termites (Isopoda).



U.S. Department of Agriculture

Fig. 37. A much-enlarged picture of a cotton boll weevil on a cotton boll. The powerful beak is used to puncture the plant for egg-laying

Their intelligence is not what it might be; they have no constructive ability except in textiles. Certain caterpillars were living in tents of their own making ages before our nomad ancestors had learned that art. Sleeping bags of silk were being constructed by other caterpillars eons before the Chinese discovered that they could unweave the thread spun into silkworm cocoons and weave it over again to suit their own purposes.



Fig. 38. Scales from the wing of a moth photographed through a microscope

Adult Lepidoptera, however, do not spin. Their striking trait, to which they owe their name, is the powdery material which brushes off easily from their wings. This, magnified, is seen to be a roofing of minute scales overlapping one another like roof shingles, each fastened to the wing by a slender point at the tip end (Fig. 38).

Like the other orders of "higher" insects (beetles, flies, and bees), the change of form (metamorphosis) in Lepidoptera is complete. The egg is laid on or near the same sort of food plant as that on which the mother was raised and on which the young caterpillars are to feed. Lepidoptera, with few exceptions, are vegetarians.

Some butterflies and moths are very particular about their food plant. It may be of the cabbage family; in which case any plant,

such as wild mustard, radish, cauliflower, or whatnot, belonging to that group will do. The cabbage smell appeals to them.

Others are less particular. Their tastes are broad and catholic. The gypsy moth will eat the leaves of almost any deciduous tree, but it draws the line at pines and other conifers.

Caterpillars (young butterflies or moths) are wormlike, voracious creatures with jaws (mandibles and maxillae) for chewing and, on the thorax, in front of the huge abdomen which carries voluminous digestive apparatus, are three pairs of ordinary walking legs. The abdomen is supported and propelled by supplementary, fleshy "pro-legs." The caterpillar (larva) when full grown, stops feeding and becomes restless. It tends to climb, or, in those moths which do not spin cocoons, to burrow. Important reconstructive changes are now going on in its body. This is called the "pre-pupa," or spinning stage.

If the prepupa is to be a moth (night-flyer with feather-shaped feel-



Fig. 39. Part of the wing of the Emperor moth of Europe showing the "eye-spot." Note the scales lying in a series of rows

ers) and a spinner, it begins to weave a shroud around its body. Silk exuding in a thread from glands just behind the head is carried back and forth in a figure-of-8 direction around its body, layer upon layer. This is the cocoon, in which sooner or later it sheds its last larval skin and becomes a pupa, with no visible legs in most cases, though you can see the sheaths in which the legs, wings, tongue, and feelers of the future moth are being formed.

The prepupa, or full-grown caterpillar, of a butterfly, however, does much less spinning. It always fastens its tail firmly to a branch or twig with silk. Then it may do one of two things. Either it swings free, head down, and proceeds to drop off its old larval suit of clothes, or it stands head up against the wall and spins a girdle across its back, fastened to the wall first on one side and then on the other. Now its larval skin bursts along the back and is sloughed off at the tail end. This is the pupa, or, as it is called in butterflies, "chrysalis," so-named by the ancient Greeks for its golden color in certain species, such as the milkweed or monarch butterfly, in which the beautiful green chrysalis is adorned with shining golden spots.

The moth pupa enclosed within the cocoon is usually plain brown, and so are the naked kinds with no cocoon which one digs up in the garden.

The chrysalis stage in summer may last only ten days or two weeks, but, generally, in single-brood butterflies, and especially moths, it lies inert during the following winter.

Eventually the fully-matured butterfly or moth bursts the skin of the pupa and walks slowly out. The moth which has to get out of its cocoon, exudes a softening excretion from its

head, and so breaks easily through the silk. Its flat, limp, baglike wings now fill up with blood and expand to full size. The insect waves them gently, which helps the blood to flow in from the thorax; then they dry out within an hour and stiffen.

Profound changes were going on even in the larva, in which the baglike wing buds were already forming beneath the skin. After leaf-feeding is over for good and all, preparation is being made in the pupa to get rid of the jaws (mandibles and maxillae) and replace them by a tongue for sucking. The hard mandibles disap-



Fig. 40. Chrysalises of the emperor moth, wintering in flask-shaped cocoons. This photograph was taken against a strong light to show faintly the pupae inside the cocoons

pear, but the maxillae, or supplementary jaws, which in the caterpillar are a pair of sensitive, finger-shaped organs playing over the surface of the mandibles, are transformed (or their stumps are) into a tongue. This is really a pair of grooved ribbons locked together along their edges to form a single hollow tube, which, in the moth or butterfly, is coiled up under the head like a watchspring between two feathery feelers (labial palps) projecting in front of the head.

Other important changes in adaptation for the new life have taken place. For example, the caterpillar had on each side of its head a row of near-sighted little eyelets (ocelli)—you could probably not make a caterpillar wince by poking at it—useful only in finding its way around the leaves of a plant. These have been replaced by the huge, ball-like, compound eyes which stand out on each side of the butterfly's, or moth's, head. You can not get very near a butterfly without being seen. Its compound orbs, made of thousands of tubes fitted together like cells of honey comb and pointed in every direction, are sensitive to any quick motion you make, even several feet away.

The caterpillar's feelers (antennae) were minute threads, well-enough adapted, probably, for the limited, gluttenous life of a worm. They are discarded for the conspicuous antennae by which you can easily tell a moth from a butterfly.

In a moth, they are large and feathery-shaped, at least never knobbed at the end as they are in butterflies. In the male moth, they are much more broadly featherlike than in the female. He is able to sense the female, or females, at a great distance, rods or even miles away if the wind is

right. That is true at least of some of the large silk-spinning saturnians. He does this by what is probably simply a sense of smell with extraordinary acuteness.

Butterflies mate in the air and visit flower clusters apparently mostly by sight, but if you will watch brush-footed (Nymphalidae) butterflies when at rest, lowering the knobs of their antennae so as almost to touch the plant, you will be pretty sure that they smell with the antennae. It is highly probable that they also have a sense of touch.

Butterflies and moths, when adult, take only liquid food, nectar from flowers, sap, and whatever juices—preferably sweet—that the country presents. Of course they cannot grow on such a diet, but have to depend for their energy very largely on their reserves of fat stored during the hungry caterpillar stage.

In midsummer their life is limited to about a month; if they hibernate, as some butterflies do, it is longer. Moths of the silkworm, having no tongue, take no food at all; they mate; she lays her eggs, and within a fortnight life for both of them is over. In this species, the eggs are laid in a hurry anywhere, sometimes singly, but more commonly in bunches.

In moths, laying in bunches on the proper food plant is very common. The gypsy moth fastens the bunch to the bark or to objects close to the base of the tree. The tent caterpillar moth glues them to a twig of wild cherry or apple, and paints them over with a kind of varnish. The resulting caterpillars from one bunch of eggs flock together and build one tent. The same is true of the mourning cloak, or *Antiopa*, butterflies which, however, build no nest.

As a rule, butterflies distribute their eggs widely, flying from plant to plant of their favorite botanical family and sticking to it a single egg. This is a very hygienic method, for crowding of caterpillars spreads diseases to which they are susceptible.

The eggs laid singly are in many cases very beautiful objects, spherical, spindle-shaped or vase-shaped, richly sculptured, and of exquisite colors, blue, green, yellow, or red, though you need to use a magnifying glass or microscope to appreciate them. They are fertilized just before laying by sperm stored up by the female at a previous mating.

One brood per year is the general rule in Lepidoptera, with exceptions. Many-brood, or "polyvoltine," strains of silkworms occur, though "univoltine" or single-brood strains are more common. Some butterflies have two or three generations each season, restricted in breeding capacity only by cold and lack of food (clover and alfalfa butterflies).

Caterpillars of some butterflies will, when half-grown, refuse all food and prepare at once to hibernate; the next spring, feeding begins, then pupation and eclosion (hatching out of the chrysalis). The resulting butterflies mate, lay, and half-grown larvae proceed to hibernate. Many single-brood butterflies (silver-spotted fritillaries, meadow browns, and skippers) do this.

Brown-tail-moth caterpillars winter in tree nests made of leaves spun together. They are unable to stand intense cold, so that the spread of this foreign species into northern New England is checked. The larvae freeze before the winter is over.

Even very delicate naked caterpillars, however, nestling close to the

roots of grass somehow adapt themselves to intensely cold winters. Probably the roots radiate some heat, and a blanket of snow protects them.

So hibernation occurs at any one of the four stages: egg, larva, pupa, adult. Only a few kinds of butterflies,



American Museum of Natural History

Fig. 41. These tent caterpillars have spun their own tent among the limbs of a wild cherry tree. This species, *Malacosoma americanum*, will emerge as an adult moth

and probably no moths, winter as adults. One of these species is the milkweed or monarch butterfly, which in the fall migrates southward in large flocks, especially to Florida and Southern California, and in the spring spreads northward singly. This is a strong flyer, widely distributed throughout the world.

In so-called temperate latitudes of North America there are five large families of day-flying Lepidoptera with knobbed antennae.

(1) BRUSH-FOOT BUTTERFLIES: These are so named because their front pair of legs are reduced to mere useless—or nearly useless—struc-

tures like feather dusters, held firmly against the body. The other two pairs are strong and rugged. Having no active front legs tends to upset their equilibrium, and when some of them, at least, alight upon a tree trunk, they swing round so as to face downward, turning tail toward the sun. Similarly, some face away from the sun when they light on the ground. It is a curious fact that most of them, as caterpillars about to become chrysalis, suspend themselves only by their tails. Their chrysalids continue to hang that way, facing down, while other butterflies, as a rule, face up. All this seems to indicate an inherent weakness in their front legs which makes them do these queer things.



L. W. Brownell

Fig. 42. The mourning cloak butterfly has dark-brown wings, with a light-yellow border, and blue spots along the edge

In this family are our earliest spring butterflies, the mourning cloak, or *Antiope*, and various anglewings, which to some extent winter as adults. They

frequent the edges of woodlands. These species may be identified by Hollands's *Butterfly Book*. For life histories, Scudder's *Brief Guide to the Commoner Butterflies of the Northern United States and Canada* is strongly recommended.

Another group of brush foots are the silver spots (of the underside of the wings), fancifully called "fritillaries" from their checkered, or griddlelike, color pattern. They winter as caterpillars, in which stage they feed on violets. The adults prefer moist, sunny meadows.

The most celebrated brush foots are the cosmopolitan monarch, or milkweed butterfly and its supposed "mimic," the viceroy. Both look much alike, but have very different habits and life-histories. The milkweed caterpillar is a yellow, white and black striped, tigerlike larva; the viceroy larva is a short, lumpy, olive-brown creature, with a saddle of white, and is found chiefly on willows. These viceroy caterpillars hibernate singly in a rolled-up leaf on their tree in the same way as do their near relatives, the banded purple and red-spotted purple, which live on birch and willow, sometimes on other trees.

(2) GOSSAMER-WING BUTTERFLIES: Members of this group are all small and delicate. There are the hairstreaks, brownish, some species with delicate wing-tails; there are, too, the Blues and the Coppers. Their caterpillars are all short and flat, shaped like a slug or sow bug. The food plants differ widely. One of them allied to the Coppers and called the wanderer (*Feniseca tarquinius*) is a strange, carnivorous caterpillar feeding on plant lice, especially the wooly aphid of the alder.

(3) THE PIERIDS: These are regarded as "typical" butterflies and resemble in some respects the swallow-tails.

The Yellows have smooth, green caterpillars which feed on plants of the pea family—clover, alfalfa, and, in sub-tropical regions, the cassias. The orange tips use mustards as their group of plants, i.e., crucifers, which they share with the Whites, to which the imported cabbage butterfly belongs and the gray-veined White, or native cabbage butterfly, which, however, seeks its crucifers not so much in gardens as in wild places (wild mustard, radish, etc.).

(4) SWALLOWTAILS, OR PAPILIOS: They are the large black or yellow species with long tail-like extensions of their hind wings. They winter as chrysalids. One of the first to appear in the spring is *Turnus* (but-



L. W. Brownell

Fig. 44. *Papilio asterias*, one of the swallowtail butterflies, lays her eggs on carrot tops and parsley. The caterpillar is green with black bands on each segment

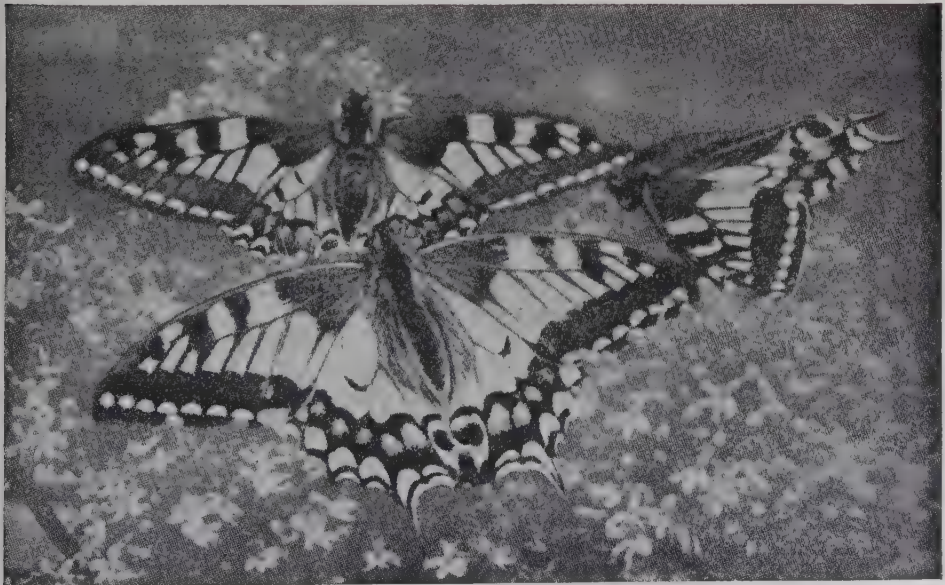


Fig. 43. Butterflies and moths both have two pairs of flight wings. Above we see three fine examples of the British swallow-tailed butterfly, a most beautiful specimen



Fig. 45. Breeding silkworms. When the cocoons have been completed they are all gathered together (as is shown above) and the silk wound on a simple machine

terflies are very likely to have the names of ancient Greek heroes). It lays its eggs on almost any sort of deciduous forest tree. In the southern states it has two sorts of females, one of them yellow, as is invariably the case in the north, and another black like the male. A single southern mother may have both yellow and black daughters, though the details of this color inheritance are unknown.

Among the black species, the commonest is *Papilio asterias* (or *polyxenes*). *Asterias* lays her eggs on carrot tops and parsley. Often one finds, on carrots, the tiger-colored caterpillar, pea-green with spotted black bands around it on every segment.

(5) SKIPPERS (OR HESPERIIDAE): These muscular, stubby little fellows are day-flyers, usually with

some attempt at a hook on the ends of the thread-shaped antennae. They are powerful flyers, considering their size, and extremely modest in their colors. The smaller species lay their eggs on grasses, the larger on members of the pea family, oaks, columbines, etc. The caterpillars are plainlooking worms with big heads and ridiculously small necks.

Skippers are regarded as a connecting link with the moths, as the veins of the wings and other structural features show clearly. They seem to be "on the fence" when it comes to holding their resting wings. Some hold them up like butterflies, others down flat like moths, some split the difference: forewings up, hindwings down flat.

Turning to the moths now, we find that they are regarded as more primi-

tive than butterflies, that is, more like the rank and file of insects in general. They are mostly night-flyers with very plain colors. There are exceptions, such as the beautiful *Utetheisa*. It is a day-flyer with exquisite pink and orange colors. It is one of the tiger moths which, as a rule, are of moderate size, with rather brilliant, spotty or striped colors. Their hairy larvae are called "woolly bears."

Some of the most important families of moths are these:

Saturnians and Silkworm moths
 Owlets or Noctuids
 Tussocks or *Lymantriids*
 Geometers
 Sphingids
 Leaf rollers
 Microlepidopteran families, including
 the clothes moth

In a continent so extensive as North America, there are so many species of moths of so many different families that one must consult one of the numerous special books for their identification. There is space here for only brief notes regarding those just mentioned.

Saturnians are giant relatives of the domesticated silkworm moth of China and Japan, cultivated to some extent in Italy and France, never very profitably in the United States. The silkworm feeds on mulberry leaves. They are voracious eaters. The illustration shows them feeding and others climbing up to spin. Also are shown some of the cocoons.

Our native saturnians include the beautiful, delicate-green Luna moth, with long wing-tails, *Cecropia*, *Polyphemus*, *Promethia* and others. Their



Fig. 46. Feeding the young silkworms with mulberry leaves. At the top of the picture can be seen the silkworms busily engaged in spinning the cocoons shown in Fig. 45.



Fig. 47. The transparent spots, one on each of its four wings, and the tails on the two hind wings make the Luna moth easily identifiable

large, green, spiny caterpillars are found on various deciduous trees, wild cherry being a favorite.

Noctuids are heavy-bodies, dark-winged, in rather plain colors. Among them, however, are the "under-wings," rather large, with protectively colored, mossy-gray forewings, and beautifully colored red or yellow hindwings, which are covered and out of sight when the moth is at rest. Their caterpillars are "cut-worms," fat, naked, dark-brown creatures, which lurk by day in shallow burrows and at night bite off the stems of garden plants near the ground. Poke around the base of the cut-off stem into the ground and you will almost always find the "worm."

Tussock moths (liparids or lymantriids) are rather plain, brownish-gray

or white moths, some of which have "tussock" caterpillars, i.e., provided with four long pencils of hair, one pair fore, one aft, and also four short, white tussocks of hair along the middle of the back. This handsome caterpillar devours the leaves of shade trees. Its mother is wingless and stays on the outside of the empty cocoon from which she emerged. Here she mates and lays her eggs in a large bunch which, if it is already autumn, winter over.

More devastating species of this family have been introduced from Europe. They are the gypsy and the brown-tailed moths, which have played havoc with fruit and shade trees in the eastern states, especially New England. The caterpillars of each have hair in tufts, all of about the same length.

The female gypsy moth is large and white, with crossbands of brown; the small male is grayish-brown, strikingly different from the female. By crossing various Japanese varieties with European ones, Professor Richard Goldschmidt has produced many intersexes—males starting to be female, and vice versa. The gypsy's eggs, laid in a bunch, usually on the bark of a tree, are covered with hairy scales from the female's body. They, too, winter over.

Brown-tailed moths are white, with a patch of long, brown, hairy scales on the end of the body. Males and females are much alike in size and color. Both adults appear in July. Their egg mass is covered by the female with brown hairs from her tail. As winter approaches, the caterpillars spin leaves together to make a rude tent, in which they hibernate.

Geometers, the caterpillars of which are "measuring worms" or spanworms, are rather delicate moths with slender

bodies. Everyone must have seen these slender, cylindrical caterpillars looping or inching along. Their peculiar gait is due to the lack of abdominal feet (prolegs) in the middle of the body, so that they alternately touch the ground first with the thoracic feet, near the head, and then with two pairs of claspers, or prolegs, near the tail. Many of them have the instinct to rest on these tail claspers and stretch the body out stiffly into the air. This makes them look surprisingly like twigs, and it is supposed that by this method they have fooled many birds which otherwise would have devoured them.

Sphingids, or hawk moths, have long, narrow forewings and very large bodies. Their tongues are long, and one often may see them at evening hovering like hummingbirds over cup-shaped flowers so deep that a long tongue is a real necessity in getting at the nectar.

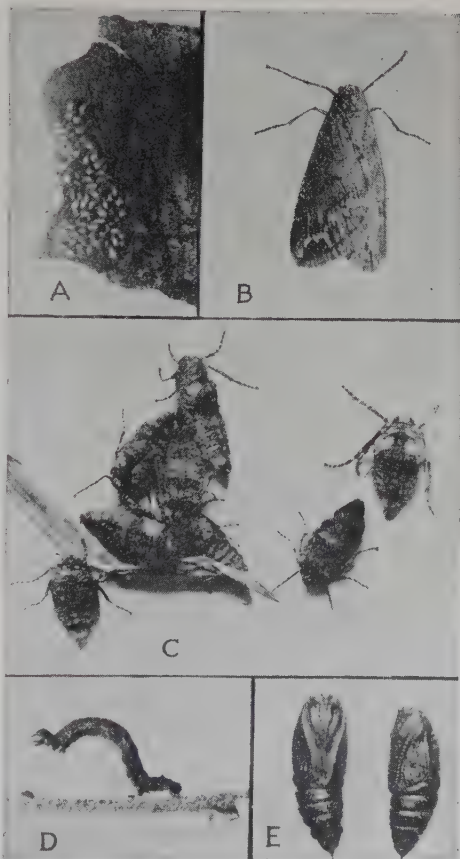
The caterpillar is a stout smooth "worm" with a harmless horn at the hind end of the body. In some species, this is reduced in size to a mere knob close to the surface. In a tropical species which feeds on the frangipani tree, the horn is replaced by a long flexible tubular filament, probably a sense organ, which may, perhaps, notify the owner of the arrival, below it, of a lizard climbing up the tree.

The pupa of hawk moths is usually buried in the ground and has what looks like a jug handle at its larger, front end; this is the sheath of the future tongue.

One of the common species is the tomato worm or five-spotted sphinx. The moth has a wing expanse of between four and five inches, ashy-gray; there are five yellow spots on each side of the abdomen. The dark-green

larva, three or four inches long, feeds on tomato plants. In the southern states a similar moth called the six-spotted sphinx, but somewhat darker, feeds as a caterpillar on tobacco plants.

Among the hawk moths are the clear-wing sphinxes, or "hummingbird moths." The wings are transparent. The larvae feed on viburnum, snowberry, and thorn bush. They spin a cocoon among fallen leaves; and the



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Fig. 48. Five stages of the spring cankerworm, or measuring worm; A, eggs; B, male moth; C, female moths; D, partly-grown larva; and E, pupae

tongue of the pupa is covered over, not exposed like a handle.

Leaf rollers (tortricids) are small moths, the caterpillars of which are naked, whitish, or pale green, which draw the edges of leaves together and fasten them by spinning. Some of them live together in colonies, weaving together all the leaves at the end of a branch, as in the cherry tree tortricid. Finally, there are many minute moths (microlepidoptera), some of which, as caterpillars, are leaf miners. These larvae are seldom seen because they burrow beneath the skin or epidermis of a leaf, but their burrows or "mines" show through upon the surface, often as long, twisting, serpentine bands.

The word "moth" to a housekeeper means none of the thousands of species included in the families of nocturnal (or mostly nocturnal) lepidoptera just outlined briefly; it means definitely *clothes moths*. Of these there are three species likely to infest our woollens: the case-maker, the tube-builder, or tapestry moth, and the naked-webbing moth, referring to the larva in each of them.

The case-making caterpillar patches bits of wool, or other food material, together with silk of its own spinning to make a house for itself. As it grows, the house has to be enlarged by slitting it and putting in a piece, as well as by building it up at the end. By furnishing it with bits of colored material, the progress of construction can be followed easily. When growth of the larva is complete and winter is approaching, the case-maker migrates, case and all, to a secure spot, sometimes upward to the ceiling of a room. After the winter sleep is over, it sheds its skin and becomes a pupa. About three weeks

is passed in that state and then the moth emerges. Its wing expanse is about a half-inch, yellowish-brown, faintly spotted, fringed with hairs. There is only one brood per year.

The tube-building tapestry caterpillar is slightly larger and not as common as the other. It makes silk-lined galleries or winding tubes, in which it finally turns into a pupa. The front wings of the adult are black on the half next the body, the outer half creamy white.

The naked-webbing caterpillar makes no case, but spins a path of silk along which it travels. It feeds all through the year, temperature permitting, and a single generation lasts about three months (egg one week; larva ten weeks; pupa two weeks).

HYMENOPTERA: It is among the ants, bees, and wasps, and to a lesser extent among the termites, that social life in the insect world reaches the peak of development. In beehives and ant colonies there are three kinds of insects: a fertile female or queen, many workers or infertile females, and the males or drones. In summer the young queen ants attain their wings and make a grand nuptial flight into the air, much like the flight of a queen bee with the drones swarming after her. The male ants fly up, too, and the strongest and swiftest flier mates with her. Then, the flight over, the queen ant bites off her wings and returns to her galleries below ground.

In such nests, certain ants keep "cows" and "milk" them. These are plant lice or aphids, which exude a sweet drop of fluid when stroked with the antennae or feelers of the ant. The aphids are herded together and driven down below to the nest, where they are fed and kept.

In the south of England, some of the ants in their foraging on the wild thyme collect the caterpillars of the blue butterfly. These likewise are driven below and become pupae in the ant nest, from which they emerge the following summer as perfect butterflies complete in every detail.

These slave-keeping ants neither feed their young nor make their nests themselves, but depend entirely on slave labor. Beetles, spiders, crickets, and wood lice are sometimes found in ants' nests as boarders.

Less complex is the social life of wasps, which also differs from that



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Fig. 49. A typical wasp nest, made largely of paper and paper-like materials. Beneath the surface is a remarkable series of channels and passageways

Among the largest and most dangerous of the fighting ants are the Amazons that march in search of their prey in serried ranks like a terrible marauding army. They raid nests of less warlike ants for the purpose of obtaining slaves. At least three species of ants keep slaves. When they raid another nest, they kill off the worker and warrior ants, and take back pupae which hatch out as slaves. Should they move their habitation, they take their slaves with them.

of bees in the shorter life of the queen and in the fact that the entire colony, except the queen, dies off with the winter frosts. They abandon their wonderful nest ball of papier mâché that is made from wood pulp stripped off old fences and posts. The young queen alone hibernates, emerging in the spring to lay her eggs and rear her grubs.

The social life of the domestic beehive, with its various duties assigned to different workers, is well-known.

There are the doorkeepers, who attack strange bees and sting them to death between the joints of their bodies, and ventilating bees who keep a current of fresh air in the hive by fanning it with their wings. Other workers collect water; others form out of wax the six-sided cells that make the maximum use of space, and in which eggs laid by the queen hatch into grubs. The queen lays thirteen times her own weight in eggs a year, laying 2,000 or 3,000 a day during the "honey-flow" of summer. Those grubs (larvae) that are given "royal jelly," a rich mixture of pollen and honey, produce queens or fertile fe-

males. The others, furnished with plainer food, hatch into workers.

A hive may have 50,000 or more workers, and 2,000 drones or males. The workers hibernate for the winter after a ruthless killing of the drones. By their visits from flower to flower in search of nectar, their hair-covered bodies mix the pollen of different plants, and thus help plant fertilization.

Between the joints of the hind leg is a fold or basket that enables the bee to carry back to the hive the pollen required as food for the larvae. Bees do not seek honey, but nectar. Honey, as we know it, is made by the bee in its honey sac, where cane sugar is turned into grape sugar by means of a ferment, or enzyme, called invertase.

Their flight range is within a three-mile radius of the hive. As in the case of most of the lower animals, bees are partially color-blind, and see red as black, green as yellow or blue, and probably see only the last color as we do.

Wasps are frequent raiders of bees' nests, especially those of the bumblebees that live in stone walls and banks. The big cuckoo bee, or *Psithyrus*, has no nest of its own. It prolongs its winter hibernation late into the spring, until the bumble bees have their nests well started. Though rare, it may be recognized by its dark, smoky wings and silent flight. Superficially it closely resembles a bumblebee; the female, however, has no pollen basket, and there are no workers in this species. The raiding bee enters the nest and, having conquered the bees guarding the entrance, is left alone. Once inside, the cuckoo bee sooner or later fights and kills the queen, and carries on the cell-making

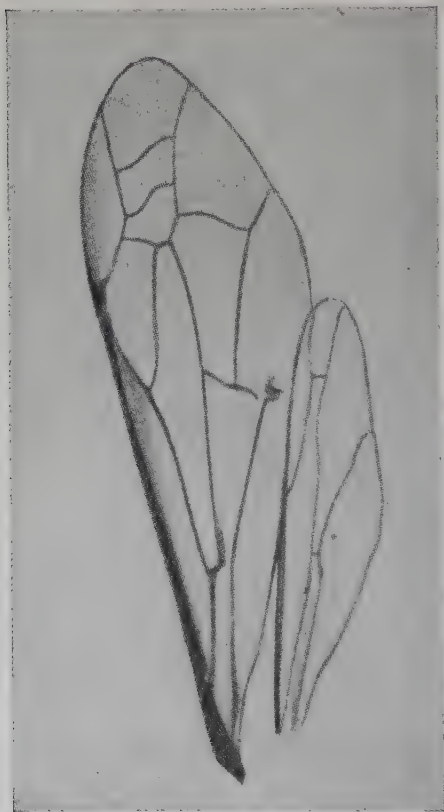


Fig. 50. Pair of wings from one side of a bee

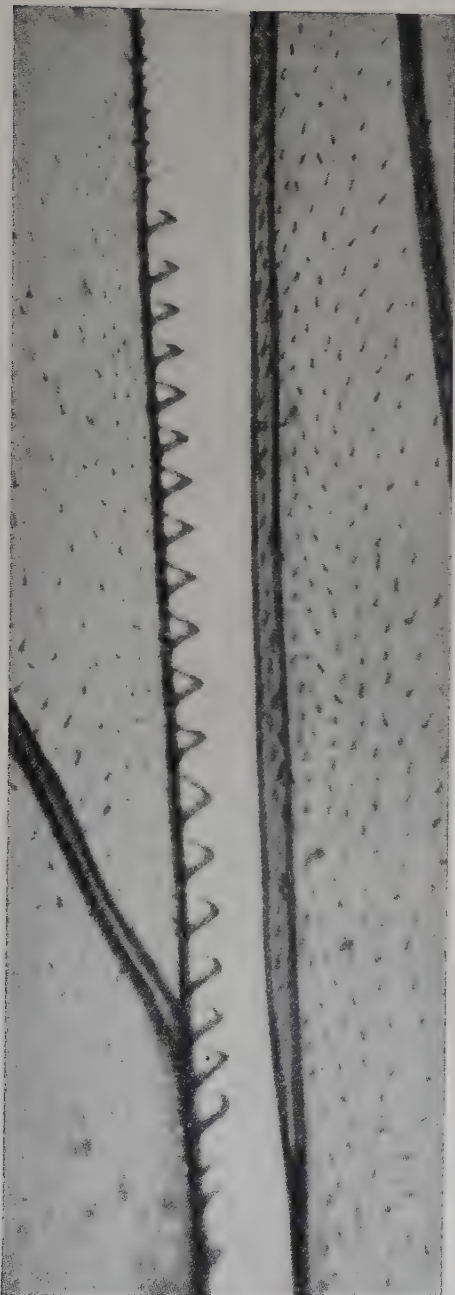


Fig. 51. The hook and eye in nature. Bees' wings have hooks and eyes by which they are linked together for flight

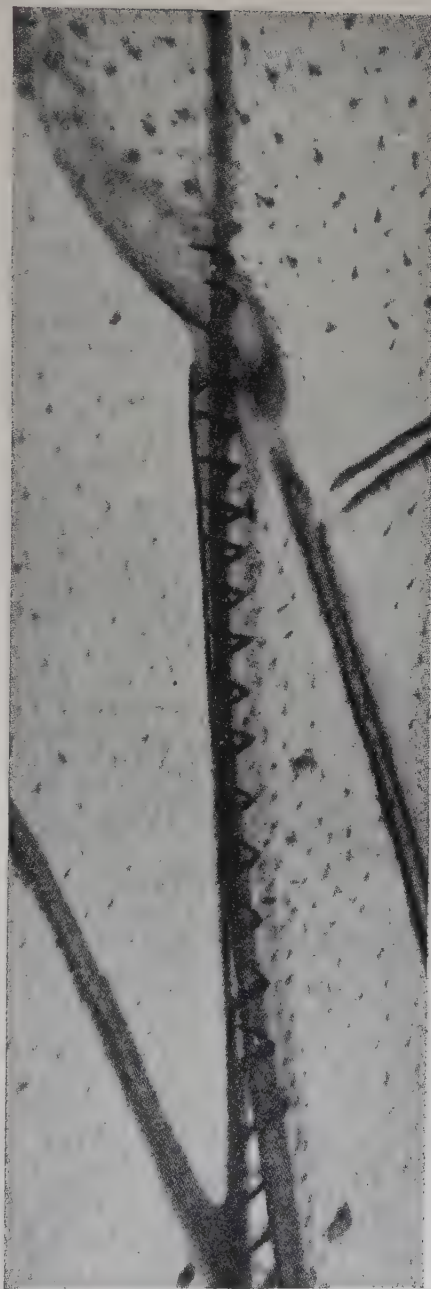


Fig. 52. In Fig. 51 the bee's wings are uncoupled. Here we see what they look like when linked together by the hooks

and egg-laying herself. The workers born from the earlier layings of the rightful queen, rear the grubs of the usurper.

Of the numerous other bees, perhaps the most interesting are the mason bee that plasters a mudlike nest; the carpenter bees that makes holes in wood; and the leaf cutter that bites small semicircles from rose leaves, with which to line its cells. The last are short-tongued bees and are closely related to the wasps.

There is a good deal of misapprehension in regard to the bee's sting, which is a development of the ovipositor, or egg-layer. It is a sharp, needlelike instrument and contains two serrated barbs that lacerate the flesh. A popular belief is that the bee stings only once and then dies. When the bee uses its sting, the pain may cause the victim immediately to brush it off, with the result that the bee has no time to withdraw its sting. The sting, engaged in the flesh by the barbs, is thus sometimes torn out of the bee's body and, as it carries part of the entrails with it, the bee dies. More frequently, however, the bee stings and runs.

If we examine the wings of the bee through a microscope we see that there are a number of little hooks along their margins (Fig. 51). These hook the front and hind wings together to form a single flying plane (Fig. 52).

Only some of the more important families can be listed here.

Sawflies. So-called for sawlike egg depositor of the female. They have caterpillar larvae which tend to twist up the end of the abdomen. Willow sawfly, "Currant worm."

Gall wasps. Larvae produce galls in plants. Oak apple, goldenrod round-gall.

Ichneumon wasps. Larvae parasitic on caterpillars or other larvae. Usually the adult lays few eggs on the victim.

Braconids. Larvae parasitic on caterpillars; numerous eggs laid by the mother wasp; full-grown larvae, after feeding on blood of caterpillar, spin silken cocoons on surface of the victim.

Proctotrypids. Smallest of parasitic wasps. Eggs laid on the eggs of insects.

Chalcids. Minute, shiny, metallic, bee-shaped. Larvae either useful parasites or destructive to wheat stems.

Ants.

Wasps.

Digger wasps. Build nests of clay, provisioned with spiders.

Mining and carpenter bees. Solitary pairs. Female constructs cells for larvae by excavating pith from stems of plants. Large carpenter bee, as large as bumblebee, tunnels in solid wood; provisions of pollen and nectar for larvae.

Leaf-cutter bees. Make tubular cells in ground or soft wood, lined with pieces cut from green leaves.

Bumblebees and guest bees.

Honeybees.

CHAPTER 21

THE LOWER GROUPS OF VERTEBRATES

THERE is a very close link between fishes, amphibians, and reptiles, for, besides being scaly creatures, they have other things in common. It was from fishes that the earliest amphibians developed. These stegocephalians ("armor-headed") inhabited the estuary swamps, spending part of their time on land and part in water. Even today our amphibians—the frog and the newt, for instance—spend their early life as free-swimming, fishlike tadpoles before they finally come ashore as cold-blooded, reptilian creatures. Millions of years ago, when the earth was becoming drier and hotter, certain of these primitive amphibians stayed on shore altogether. They developed dry, scaly skins like present-day lizards and snakes.

Although the general description of a fish is a creature with scales and fins living in water and breathing through gills, this is not true for all. There are some fishes—the toadfish is one—that have no scales. Others, such as the climbing perch of India and the mudskipper of West and East Africa, come out of the water and use their fins for locomotion. The mudskipper is able to climb about the mangrove swamps because its moist tail is specially adapted to breathe the water in nearby pools.

In the primitive sharks, rays, and sturgeons, the scales take the form of plates of enamel. Indeed, they are more akin to teeth than to scales as found in other fish. Ordinary scales are epidermal, or skin growths, growing in rings much like the woody

trunk of a tree. There is another resemblance to trees in that the rings show spawning marks, and by counting them with the aid of the microscope it is possible to tell the age of the fish. Incidentally, the otoliths, or ear bones of a fish, also enable us to tell its age in a similar manner.

The *fishes*, *amphibians*, and *reptiles* are classes of that main division of the animal kingdom to which we belong, viz. the vertebrates. The other classes are *birds* and *mammals*.

FISHES

There are four main groups or subclasses of fishes: lampreys, sharks and rays, true fishes, and lungfishes, here arranged in the order of their complexity or stage of development in the process of evolution. The simplest and lowest are the lamprey eels.

LAMPREYS: Most of the lampreys and their relatives, the hag fishes, live a part of their lives in the sea. They



New York Aquarium

Fig. 1. The mudskipper, from the mud flats of the East Indies, where it skips about using its modified pectoral fins as limbs

are eel-shaped, swim near the bottom, and attach themselves to rocks by their circular mouths which work like suckers. They have no real jaws, but there are sharp teeth surrounding the mouth; in the middle of it there is a rasping tongue which, when drawn in, produces strong suction. These creatures are parasites. Attaching themselves to a fish or other victim, they bite a hole through the skin and suck the blood.

They breathe through a row of seven (or more) pairs of holes extending backward behind their small eyes. These open into pouches containing the gills and connected with the gullet. While feeding, a lamprey cannot breathe by taking water into its mouth and passing it out through the gills like other fishes. So in the lamprey, water enters and passes out through the same external openings. The hag fish takes in water through its nose (a single, median nostril), then through the gill sacs, and passes it out through the pairs of holes.

The skeleton is simply of gristle (cartilage) like that of sharks. Taking in no solid food, there is no need of a stomach, so its gullet opens into the intestine, which digests and absorbs the blood and soft tissues of the unwilling host, the fish to which the lamprey is attached.

Several kinds of lampreys live entirely in fresh water, and all lay their eggs there. The lake lamprey, abundant in the lakes of central New York, is a land-locked variety. They leave the lakes in the spring, to migrate up the creeks. They rest by day and travel by night, until they reach the shallows where they make their nests.

SHARKS AND RAYS: Like lampreys, the sharks and rays have a

skeleton of cartilage rather than bone. Their big mouth is a slit on the underside of the head. In it are several rows of very sharp, triangular teeth which are simply greatly overgrown scales with which the body is everywhere covered. These are minute plates of bony substance embedded in the skin, covered with enamel which is usually raised into a little spine. These platelike scales are called "denticles."

There are on each side of the throat five or more slitlike gill openings, instead of one gill cover (or operculum) over the whole set of gills as in the true fishes.

Another characteristic of most sharks is the unequally lobed tail; the upper lobe is larger and the end of the spine runs into it.

Rays and skates are flattened above and below, right and left sides greatly extended; thus they are adapted for life on the sea bottom. Otherwise their organs are much like those of sharks and the dogfishes.

Most sharks are viviparous, that is, the mother gives birth to fully formed young able to shift for themselves. Others lay a few large eggs, each covered with a tough, horny capsule. In the Australian bullhead shark this is spirally twisted with two long, twisting wirelike holdfasts at one end. Skates' eggs are in elongated, squarish, flattened capsules with a holdfast at each of the four corners. Some dogfishes make a similar capsule, but our smooth dogfish is viviparous.

The male shark, and especially the skate, can be distinguished from the female by a pair of long rodlike claspers projecting backward on each side of the base of the tail.

The smooth dogfish, common off our coast from Cuba to Cape Cod,



Fig. 2. Four well-known sharks (1) Basking, (2) Hammerhead, (3) Thresher, (4) Blue

and occasionally northward to the Bay of Fundy, feeds mostly on small fish and crabs, but is not at all restricted in its diet. It is harmless, but not much liked by fishermen when looking for members of the true fish group. Properly prepared, it makes extremely good eating.

shark can charge and secure an ample quantity with ease.

Sawfishes are sharklike rays, from the snout of which projects a long, coarse saw with a row of enameled teeth set in sockets along each edge. They are found in the Gulf of Mexico and along the Florida coast, chiefly



U.S. Bureau of Fisheries

Fig. 3. This is *Lepisosteus osseus*, a long-nosed gar. Its overall length is 29 inches

The big, basking shark, which basks on the warm surface waters with only its dorsal fin showing, often attains a length of 45 feet. If gashed by the propeller of a passing liner, it is sometimes washed ashore and almost invariably hailed as a whale, although the gill slits in the side of the head and vertical tail clearly show it is not a mammal. The hammerhead shark has an enormous hammerlike head with eyes at each end (Fig. 2), as well as nostrils running nearly the whole front edge of the hammer. It is a swift-moving shark, with a keen sense of smell (or taste) for spilled blood. It is rarely over 12 feet in length. The thresher shark receives its name from its alleged habit of rounding up shoals of fish by threshing the water with its tail. It has a very long tail fin, and the fish are frightened into a mass into which the

in the mouths of rivers, where they attack schools of mullets and other fishes on which they feed. The young, born in spring and summer, have a protecting sheath over the saw, so that they do not injure the mother.

TRUE FISHES: In the true fish the mouth is at the end of the body, not under it as in sharks, nor is it a mere sucking disc as in lampreys, but a real mouth provided with numerous sharp little teeth. The skeleton is not just gristle, for now—and this is the first time in the evolution of the animal kingdom—one finds true bone taking the place of cartilage (gristle).

Some of the simpler, more primitive kinds of true fishes hardly qualify under the definitions just given. For instance the hard-shelled Bichir of the Nile with an enamel coat of mail

and a row of spiny fins along its back is only getting to be a true fish. Most of its relatives are extinct and known only as fossils.

The same is true of the garpikes, or bony ganoids ("ganoid" means "lustrous," referring to their shiny coat of mail). Most of these are extinct, but *Amia*, otherwise known as mud-fish, bowfin, or fresh water "dogfish," still lives in the Great Lakes and the swamps of the Mississippi Valley. It has facetiously been called the "lawyer" because "it will bite at anything and is good for nothing when caught." It is usually about one and one-half—but sometimes two and one-half—feet in length. It is very voracious. As it has a lunglike air bladder connected with its throat, it lives for a long time out of water.

The huge alligator gar of Cuba and streams about the Gulf of Mexico is

20 feet long and has a long snout like its namesake. None of the gars are fit to eat. Even a dog refuses to bite through their coat of mail and their flesh is soft and mushy.

Sturgeons and paddlefishes are other tribes admitted by courtesy, as it were, to the group of true fishes. Again the skeleton is mostly cartilage, the small mouth is beneath the head, and the tail has the spine running into the upper tail-lobe, all of which are shark traits. But the mouth is suckerlike and the teeth are small or absent altogether. The body is protected by rows of large bony plates on which are hooked knobs. The sturgeon is a clumsy bottom-feeding fish. Some species are four to six feet long and edible; their eggs are used in making caviar. Many species migrate from the sea up the rivers to spawn. The lake sturgeon of the Great Lakes

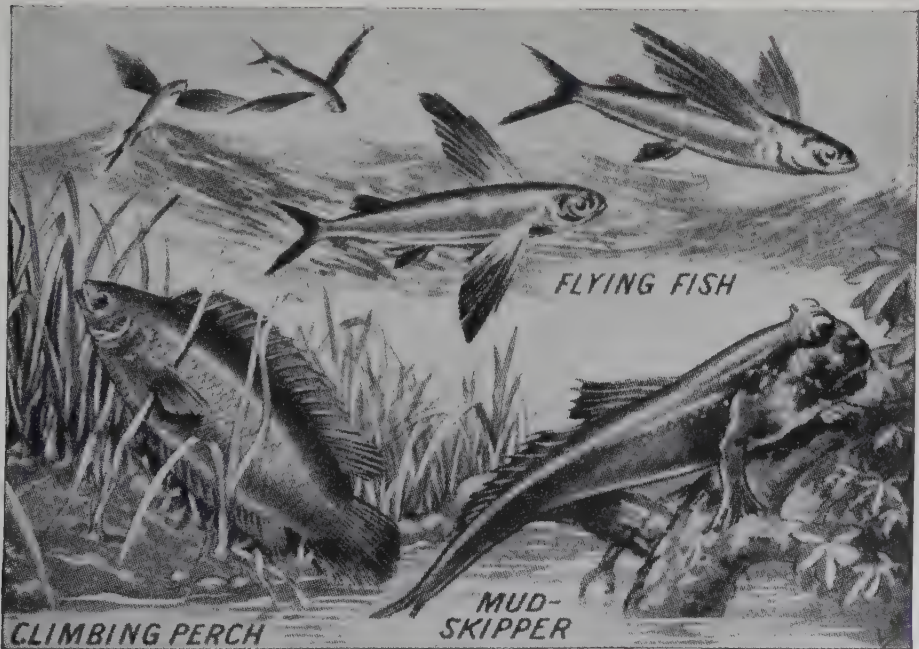


Fig. 4. Some curiosities of the sea; fish that fly, skip, and climb



Fig. 5. These silver-whip anglerfish are found six hundred fathoms below the sea. The ray which hangs over the broad mouth is seen above

and Mississippi Valley never goes to sea.

The paddlefish of the Ohio and other large rivers of the central states is four feet or more in length. It has a paddle-shaped snout over a foot long which is used to stir up the mud from which it extracts its food: worms, insects, crustaceans, and other small organisms.

We now come to the true fishes which deserve the name. Often they are called bony fishes because they have a real bony skeleton of many bones, as one discovers with some misgivings when eating shad, haddock, and certain other representatives of the group.

Fins are chiefly used by the fish for balancing in the water, as we can see when a goldfish is at rest. It is the tail, with its big caudal fin around it, which, if swept from side to side, drives the fish forward. Usually there is a dorsal fin on the back of the fish; two pectoral—or shoulder—fins, corresponding to our forelimbs; two pelvic, or hip, fins, corresponding to our hindlimbs; and the anal fin. In some

fishes—such as the stickleback and the perch—in which the rays of the dorsal fin are very strong and slightly projecting, they are used for aggression. In others—such as the great sailfish of the Pacific—the dorsal fin is developed to an enormous size, and it is unusually large in the sharks.

In some of the angler fishes, a ray from the dorsal fin is so developed that it hangs over the gaping mouth of the fish as it lies on the sand or mud (Fig. 5). With an attractive tip, illuminated with phosphorescence in some deep-sea fishes, it lures small creatures to swim up to investigate, when they are immediately entrapped by the jaws below.

Not all fishes are confined to the water. Some, such as the lungfishes, which we shall meet a little later, are definitely on their way, in the evolutionary succession, toward terrestrial life. Others leave the water for short periods, such as the flying fishes of the Gulf Stream and tropical seas everywhere, which leap from the water and glide long distances through the air.

The climbing perch of the East Indies has a peculiar twisted membrane in the front of its gill cavity which serves as a lung when it leaves the water and reputedly climbs up the wet surface of neighboring palmyra trees. By means of spines on its gill cover, it climbs somewhat sidewise six or seven feet up the trunk of the palm. In the water, it breathes as any fish does with normal gills, to which the twisted membrane for air breathing is supplementary.

In the mudskippers of the coasts of Asia and Polynesia, the eyes project above the surface of the head. The fins are strong, and it skips, like a lizard after its insect prey, over the

surface of wet mud and sand; and it skims with great speed over the surface of the water.

A fish breathes oxygen, of course, but this oxygen is in solution in the water. When we see a fish constantly opening and closing its mouth, it is not really drinking, but is gulping in mouthfuls of water. This water flows over the gills and out of the neck, either under the gill plate, or, in the case of the shark, through the slits of the neck. As it passes over the gills the oxygen is absorbed from the water by the blood vessels in the gill rakers. These are very numerous, presenting as large an area as possible to the water in order to insure an adequate supply of oxygen.

When a fish is taken out of water it dies, not because it does not have enough oxygen, but because it is suffocated. There is no water passing over the gills to keep them open, hence the rakers collapse into a heap. Although there is plenty of oxygen in the air, the gill rakers are in contact with it only through their too small outer surface.

A fish will drown if it is kept in water that lacks oxygen, as, for instance, in an aquarium tank that is overcrowded with more than about an inch of fish per gallon of water, or one that has the top of the water covered. That is why water direct from the main is not good for keeping fishes, and is best stood out awhile in

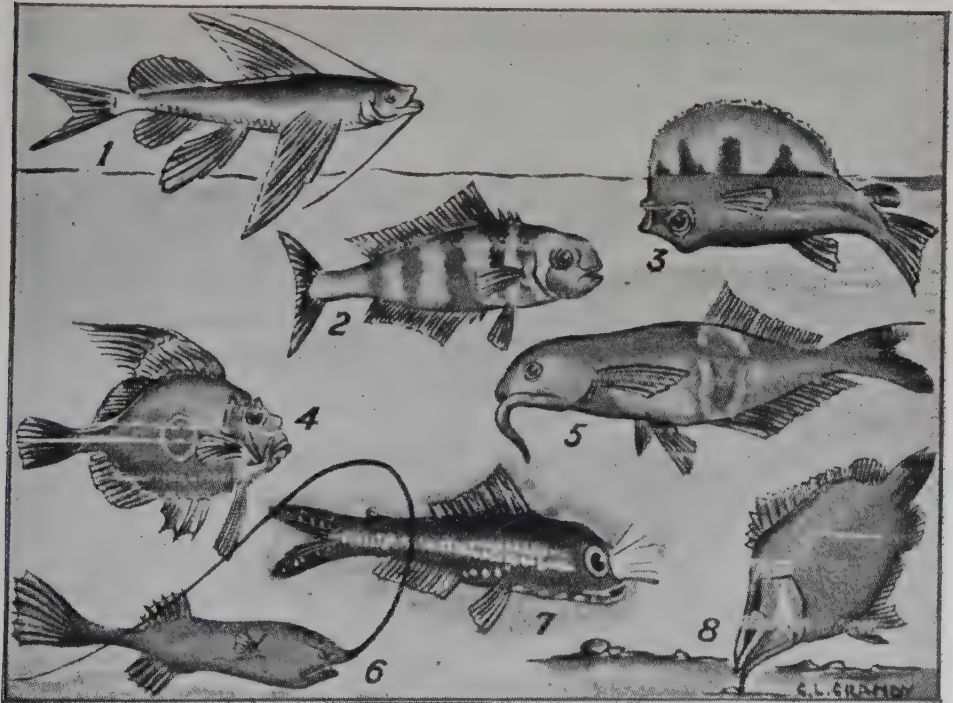
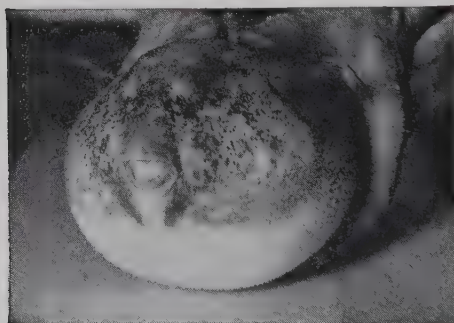


Fig. 6. Some curious fish, showing how development in certain directions has modified the original form. (1) Flying Fish, (2) Pilot Fish, (3) Puffer Fish, (4) John Dory, (5) Proboscis Fish, (6) Angler Fish, (7) Light-bearing Fish, (8) Leaf Fish

the air. Aquarists grow pond plants like *Vallisneria*, *Sagittaria*, and *Elo-dea* in the tanks because these plants give off oxygen in sunlight, thus aerating the water.

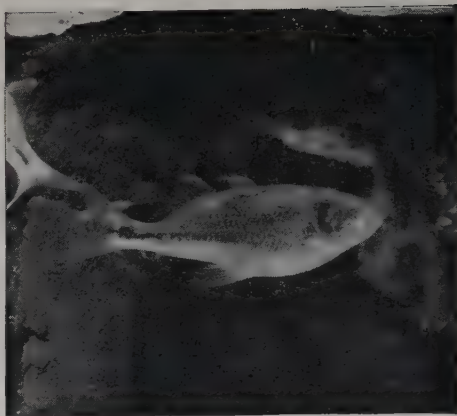
Most fishes have an air bladder just above the stomach, an offshoot of the gullet that helps to adjust them to varying pressures in the water. It helps the fish maintain its position in the water. In most fishes it is a closed sac, the gas in it being secreted from the blood, though in the infant fish directly after hatching there is an airduct which soon becomes closed. Primitive fishes, such as the gar pike and *Amia*, the mud fish, have lunglike air bladders connected with the throat. They come to the surface to gulp in air. The same is true of the lungfishes, a group which shows strong resemblances to the Amphibia. They are on their way upward in the march of evolution.

The puffer of the Atlantic coast and other globe fishes have the habit, when irritated, of swallowing air into a special sac beneath their throat, so that the belly swells out and they become inflated like a football. They



New York Aquarium

Fig. 7. This stout fellow is known variously as Harper's Puffer, Harper's Swellfish, or Harper's Blowfish. He is *Spheeroides harperi* from the southern coast of Florida



New York Aquarium

Fig. 8. The blind cave characin, found only in a single cave in San Luis Potosi, Mexico. It is the only warm-water cave fish known, all others, including the blindfish of Mammoth Cave, are cold-water fish of the type found in rivers and oceans the world over

rise to the surface and float upside down. When they become calm they deflate, but if taken out of the water and rubbed, they swell up again.

The porcupine fishes are globular in shape and covered with long spines. A common species in tropical seas reaches the length of two feet or more. It has the reputation of being poisonous.

ANATOMY OF FISHES

As seen in the figure of the anatomy, the heart receives venous (dark) blood into the auricle which opens into the highly muscular ventricle, which then pumps it into the gills. There it becomes aerated and is collected by the five (unshaded) pairs of vessels leading into the main artery (aorta) which distributes the purified, oxygenated (unshaded) blood through smaller arteries to all parts of the body. The fish's heart is a simple, two-chambered pump.

The main nervous system of the fish is a thick-walled, soft tube lying in a subway made by the bones of the spinal column, which send up slender protecting bones over it, like the arch of soldiers' guns at a military wedding. In the head it swells out into the brain. The fish, depending largely on its eyes in chasing its food, has very large optic lobes and a spacious cerebellum to take care of its locomotion and balance, but its thinking organ, or cerebral hemispheres, is decidedly below par.

The eyes of fishes are in almost every case large and staring. Having no lids and little mobility, the eye lacks expression. The lens is nearly spherical, which means nearsightedness but good strong magnification, just right for examining small prey at close range. The pupil is wide, admitting plenty of light, which is useful while swimming in the poorly-lighted depths.

A curious little four-eyed fish of tropical America at first appears to

VERTEBRA OF COD-FISH

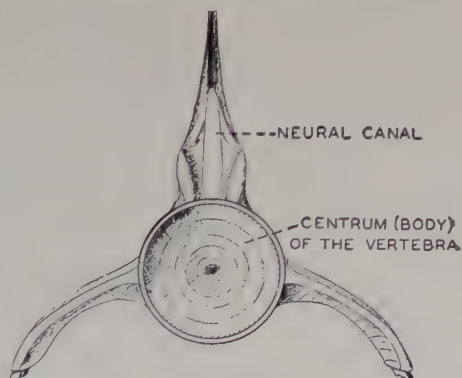


Fig. 10. Section of the vertebra of a cod-fish, showing the canal which carries the nervous system regulating the motor activities of the fish

have really four distinct eyes, but on closer examination these are found to be only two. Each is divided into halves; one, with flatter surface, for seeing above water and one, more convex, for seeing below water when the fish swims along the surface. There are two pupils, in the divided

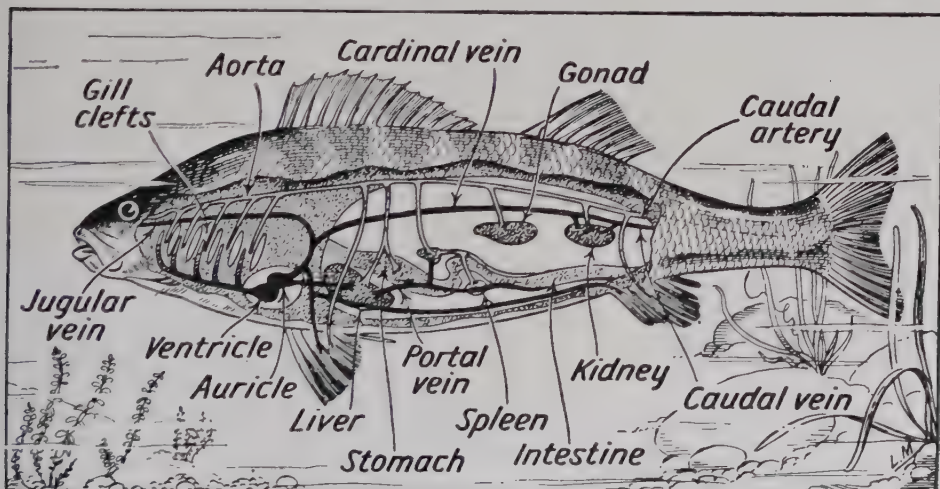


Fig. 9. The anatomy of the fish. Fishes (*pisces*) form a class of the *Phylum chordata*. They all live in the water and all except the lung fish and mudskipper breathe only through gills

iris, but only one lens. This fish, *Anableps* by name, is closely related to the famous "blind" fish of the Kentucky and Indiana caves, *Typhlichthys* (blind fish), which has eyes in early life that become defective and useless in the adult.

Flounders have a marvelous life story. They do not start life as flat fish but as fish of ordinary shape. Gradually one eye begins to grow round to the other side, and the fish tends to lie more and more on the eyeless side. When it reaches the adult stage both eyes have worked round to the one side; and the eyeless side becomes white, while the other is dark sandy-brown.

Experiments have shown that some fishes react with fin movements, or even by swimming away, when low-pitched sounds are made beneath the surface or close to the water. They probably are deaf to sounds of high pitch and to differences in tone.

They have nothing like our external ears, nor eardrum and chain of minute bones which conduct sound waves inward, nor any spiral organ (cochlea) of the internal ear by which we hear different tones. But they do have internal ears corresponding to our semicircular canals (balancing organs) and the tiny sacs with which these delicate tubes are connected. One of these little sacs (in each ear) is probably their hearing organ.

Some fishes are endowed with the power to make mysterious noises. Sea fishermen have often heard the bark of the conger eel. In the Indian trigger fish a sonorous sound is produced when certain bones connected with the swim bladder are rubbed together. The gurnards make a rattling noise with certain bones in the head. Coffer and globe fish can growl. The Ama-

zonian lepidosiren, a lungfish, emits a deep growl; the Australian ceratodus can be heard to growl when it fills its lungs at the surface. The Egyptians called the horse mackerel the "snorter" because it grunts like a pig. The little seahorse—one of the pipefishes with a curious prehensile tail with which it clings to seaweeds, a horselike head, and a quaint upright swimming motion—is said to make a noise like the distant beat of drums.

There is a fairly well marked line dotted with nerve centers along the middle of the side of a fish. This is called the lateral line and is thought to detect mass movements of the water against its sides as it swims or as a current passes over it—a very delicate organ of pressure sense.

Some fishes—such as the carp, catfish, and barbel—have tiny feelers or barbels projecting from the lips of the mouth. These always signify that the fish is a bottom feeder, for it uses these barbels to feel its way along the bottom.

Fishes have a much keener sense of taste than we do. Our "taste buds," or sense organs of taste, are found only on the tongue and inner surface of the throat but in the catfishes, carps, and suckers, they are scattered over practically the whole surface of the body, especially on the barbels. So the fish tastes its food before it seizes it, outside its mouth and not within it.

The sword fishes (Fig. 18) of the Indian, Pacific, and Atlantic Oceans are among the most predatory and savage creatures of the sea. Their jaws are prolonged into long, tapering, serrated swords. In some species 11 feet in length, the sword is about a yard long. They feed chiefly on cod and tunny (Fig. 18), stabbing with

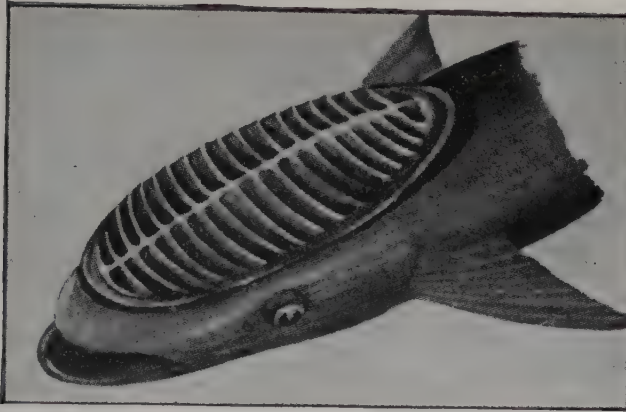


Fig. 11. Head of the sucker fish. The sucker is used for clinging to a shark's belly. Sucker fish are related to the tunny

their swords, but sometimes they even attack whales in the same way. Perhaps the most dreaded of all fishes, however, is the barracuda (Fig. 18) of the South and Central American coasts, with its ferocious mouthful of gruesome teeth.

A contrast to these fearful creatures is afforded by the pilot fish (Fig. 6). It was regarded as sacred by the ancients, who believed that it guided them towards land, disappearing when the latter was approached; they also believed that its presence warned bathers of sharks. It is remarkable for its rounded belly and deep blue stripes. Today it continues to follow both ships and sharks, but not as a guide.

Another shark-follower is the shark sucker, or remora, which attaches itself to a shark just behind its mouth where it can easily pick up crumbs which fall from the table of its host. It is not a parasite, for it does not hurt the shark, but merely is a guest or tablemate.

The curious fighting fish of Siam are relatives of the perch. The natives

use them for prize fights, wherein the fish charge and counter-charge, and as they do so, increase the brightness of their lines. Ultimately one fish is vanquished and retreating to the corner of its jar, loses its vivid coloring. Strange to say, neither fish seems to get damaged by these combats.

The pike and pickerel are the most ferocious of our freshwater fishes. The former is dark gray-green, with a long nose. It kills large numbers of young ducklings and small aquatic creatures, and will even attack bathers without provocation.

If we look at the sides of a fish we see that in most of them the upper surface is dark and the lower surface light, thus affording an efficient camouflage from foes above and below. This is particularly evident in the leaf fish of the Amazon (Fig. 6); this, like certain tropical butterflies, is shaped like a leaf. Its enemies are frequently deceived by its resemblance to dead leaves that have fallen into the water.

Many fishes living among coral reefs in the tropics, where light is strong and bottom colors brilliant, have gorgeous hues which in some species change rapidly from one color phase to another adapted to the immediate background into which they move. In the Tortugas and at Bermuda are wonderful coral formations, the beauty of which is enhanced by shoals of fish of glorious hue. These have been observed and photographed by means of deep-sea obser-



Popular Science Magazine

Fig. 12. Beebe's "bathysphere" or deep-sea observation chamber by which descents for observing tropical fish have been made to 3,000 feet

vation chambers equipped with all the necessary apparatus for a prolonged stay at great depths for purposes of scientific investigation.

Tropical fishes in general lurk in places where their colors protect them; blue tints are seen near the surface, which is more highly satu-

rated with blue; red and yellow mottled hues nearer the bottom.

At great depths in the ocean, 500 to 4,000 fathoms, where there is hardly a trace of light, all fishes are black or violet-black, unrelieved by any markings. In this universal black-out, luminous spots over light-producing glands, often on the head, help in getting about, avoiding accidents, and hunting for food.

The mysterious cold lights of the sea—the phosphorescent fishes—have been studied intensely, for there are many of them. These lights waste no energy in producing needless heat, and their origin is probably similar to that of the firefly, in that it is a bio-

logical combustion or oxidation. Research has shown that this cold light of the deep-sea fishes, which often studs their bodies as with little white lanterns, is due to two substances, luciferin and luciferase. The former is the fuel burned for the light, and the latter a kind of ferment necessary for the work but not itself changed in the process.

The first light-bearing fish was dredged from the ocean depths in 1810. It was a little black fish marked with many round white spots, and was named *Myctophum*. Not until some time later was it found that these white spots are cold lights useful in the black depths. The luminous spots



Fig. 13. Some of the gorgeously colored, tropical fish found in the Tortugas among the coral at the foot of the reef. (Above) the yellow goatfish and (below) the yellow grunt

are called photophores, or light-bearers, and later studies have shown that these luminescent fish swarm at 1,500 fathoms or so. Some of them come to the surface at night or during storms on dark days and are sometimes thrown by the waves upon the decks of small vessels.

imposed electric plates along the posterior end of its six to eight-foot body, and with them it kills fish for food and protects itself from dangerous enemies.

The electric ray called the torpedo has two kidney-shaped electric organs, one on each side of the head. Each is



N.Y. Zoological Society

Fig. 14. These phosphorescent fish, found only at great depths in the sea, give off a cold light. This light is produced by two substances, luciferin and luciferase

The angler fishes (Fig. 6) live in the deep seas and have the first dorsal fin modified into a kind of fishing rod. At the tip is a light that acts as bait to lure inquisitive fish near enough to be snapped up.

Some fishes are charged with electricity and can inflict electric shocks. In the New York Aquarium the discharge of an electric eel has been made to light a neon tube. The eel-shaped fish, which comes from Guiana and the Amazon, is one of the most dangerous of nature's electricians. It has a series of super-

composed of from 300 to 1,000 hexagonal prismatic columns arranged side by side. Each column in turn consists of about 500 superimposed plates or discs, separated from one another by albuminous liquid, and resembling the voltaic pile mentioned earlier in this book, in our chapter on Electricity.

Each column is plentifully supplied with nerve cells, a rich plexus of nerves entering on one side and dividing into a large number of finer nerve fibrils. These penetrate the deeper substances of the plates and end

blindly. When the fish is annoyed, the innervated surface of each plate becomes galvanometrically negative to the other surface, an electric current being produced that gives out a shock similar to that from a Leyden jar.

The torpedo is found in warmer waters along our Atlantic coast, rarely north of Cape Cod. If five feet long, it will weigh about 75 pounds, but those over 30 pounds are seldom captured. It is known to reach a weight of 200 pounds. The smaller electric ray of the Florida waters, especially the west coast, is seldom over two feet in length.

The electric catfish of the Nile and Congo is another dangerous electrician, having some four million electric plates scattered over its body skin. The stargazer, found off the Atlantic coast from New York southward, has a small electric battery behind each eye. It gets its name from the position of its small eyes on the top of its head, making it impossible for the fish to look sideways. It lies buried in sand with only eyes and nose uncovered waiting for little fishes and crustaceans to come along and be given an appropriate shock. It reaches a length of about a foot.

Unlike the skates, which produce only a couple of large yolk-filled eggs each in a protective capsule, bony fishes lay an enormous number of small eggs. Vast numbers of young fish result from the prodigious numbers of eggs that are laid by each fish—25,000 by the herring, 9,000,000 by the cod, and 11,000,000 by the ling. Mortality is so great, however, that comparatively few survive to maturity.

Generally these eggs are laid in shallow water, on sand or gravel, and the sperm or "milt" of the male is

deposited over them, each egg being fertilized by a single sperm cell.

Several groups of bony fishes, however, are viviparous, like most sharks. In these fishes, copulation takes place; in the male of the little swordtail minnow of Mexico, a long sword-shaped extension of the tail fin is used in this process. Comparatively few young, of course, are produced by viviparous fishes.

In the spring, from the deep waters of lakes and ponds where they have spent the winter, perch, pickerel, and other freshwater fishes migrate to the shallow waters near shore to spawn.

Certain marine fishes (salmon, shad, and striped bass) ascend rivers up to their shallow sources to lay their eggs. Eels do just the contrary—they spend most of their lives in fresh water and go down to the sea to spawn.

The instinct of the salmon to spawn in the small streams is so strong that they travel upstream often more than a thousand miles, against roaring rapids and over towering dams. They take no food during this migration, and arrive emaciated, often bruised and mutilated by the rocks over which they have had to leap. Most of them die soon after spawning.

The young, when old enough to travel, make their way down to the sea, where they remain usually not far from the river's mouth till they are five years old and sexually mature.

No less strange is the story of the eel, found as adults in fresh and brackish waters almost all over the world. Only in recent years has it been learned that mature eels, descending the rivers to the sea, by a marvelous instinct find their way to their distant breeding place in the dense weed of the Sargasso Sea,



Fig. 15. The wonderful life story of the eel, which begins its existence in the weedy Sargasso Sea near the Bermudas, travels across to Europe with the Gulf Stream and returns to spawn

southwest of Bermuda, where they spawn and die.

The minute eggs hatch each into a thin, transparent larva with flat sides, sharp at both ends, named *Leptocephalus* ("leaf-head") before its real nature was understood. Migrating away in deep water, at the end of the first summer they are about an inch long. Then they rise to upper levels, where many are helped on toward Europe by the Gulf Stream. Others swim toward North America, and by the time they near our coast they are eel-like in shape, though they remain transparent till they reach the fresh and brackish waters just off the coast, when they darken and in great swarms migrate up the rivers.

Out of the lakes of central New York into the surrounding streams there are spring migrations of that primitive fish, the lamprey, for spawning. During this period, the only food of this parasite is the blood and flesh of other fishes to which it attaches itself by its suckorial mouth. The horned pout or catfish, a sluggish, soft-skinned fish is frequently attacked.

The little brook stickleback is one of our most interesting fresh-water fishes. As in the case of some other fishes, it makes a nest. In spring when the fish spawn, the male stickleback takes on a handsome coppery-black color. He bites off pieces of pond weed to make a little nest for his progeny. In this nest, which is shaped like a barrel open at each end, the female stickleback lays her eggs, and the male sheds his milt over them in order to fertilize them.

His mate then takes no further interest in them unless she tries to eat them, but he mounts guard, fanning his fins to keep a constant current of fresh water moving over the precious

eggs. Should any other fish dare to approach too near, the stickleback charges, and may rip open its belly with the sharp spines on his back. When the young hatch, the male breaks away the upper part of the nest to leave a mere cradlelike structure for them. Should any fry stray too far from home, he merely follows, sucks them into his mouth, spitting them out again into the nest! The life story of this interesting little fish is illustrated in Fig. 17.



New York Aquarium

Fig. 16. The Portuguese man-of-war floats on the surface of the water by means of the bladder-like sac seen above the water line in the picture above. He frequents the waters of the Gulf of Mexico and has a painful sting

There are other fishes that make nests. In the muddy streamlets of the sugar marshes of Guiana, the hassar, one of the tropical catfishes, makes well-formed nests of grass blades and leaves.

Another marvel of fish life is the freshwater bitterling that, by means of a long extruded oviduct, lays its eggs inside the shells of freshwater mussels. The male Chinese paradise fish sucks in a mouthful of bubbles and carries them below the surface to a nest under water. After the female has laid her eggs, he puts them inside this nest of bubbles for protection.

The salmon makes a shallow trench, or redd, in which it deposits its eggs. The North American butterfish lays its eggs in an old oyster shell, the female coiling herself around them to keep guard. This is an unusual procedure, for any "mothering" after the eggs are laid is usually done by the male fish. The bowfin bites off bits of weeds until it has made a clearing in the river vegetation. He brings the female fish through the narrow entrance and here she lays her eggs, after which the male guards the nest and its contents.

The male seahorse carries its eggs in a pouch beneath his tail where the female lays them. Recently hatched horned pouts follow the parent through the pond in cloudlike, dark swarms. When he turns, they maneuver about him. This school of little fish should perhaps be called a kindergarten.

FOOD FISHES

Of all our food fishes perhaps the most important is the halibut, a huge flounder having both eyes and the colored surface on its right side. It lives in deep, cold water in northern

seas around the world (north of New York and San Francisco). It feeds on fishes and crustaceans, chasing them along the bottom, sometimes following them to the surface. To capture a fish, it beats its prey vigorously with its tail. It reaches a length of nine feet and weight of 700 pounds, but those over 400 or 450 pounds are rarely taken. The egg mass, or roe, floats upon the surface. Frequently it weighs over 40 pounds and contains over 2,000,000 eggs.

The great tunny, now more often called tuna, its Spanish name, is a huge relative of the mackerel. It lives in warm seas as far north as Nova Scotia in the Atlantic and northern California in the Pacific. It reaches a length of over 10 feet and weight of 700 pounds. Like mackerel, it is handsomely colored, a dark steel-blue with iridescent tints of pink and green, silvery-white below.

The John Dory (Fig. 6) of shallow waters along the coast of Europe reaches nearly a foot in length. It is a striking object in the fish market, with its oval compressed body and long dorsal spines. It is of a burnished golden color with a dark brown patch on each side, this being said to be the imprint of the hands of St. Peter when he took the tithe money from the fish! The John Dory is always an interesting object in the aquarium, for its telescopic mouth has the uncanny capacity of suddenly engulfing a prawn that is swimming far out of normal reach.

The immense popularity of modern aquarium-keeping has introduced to many homes the brilliant beauty of tropical fishes. Among these is the neon tetra with its brilliant crimson, bright emerald-green, and shimmering silver; and the angelfish with its

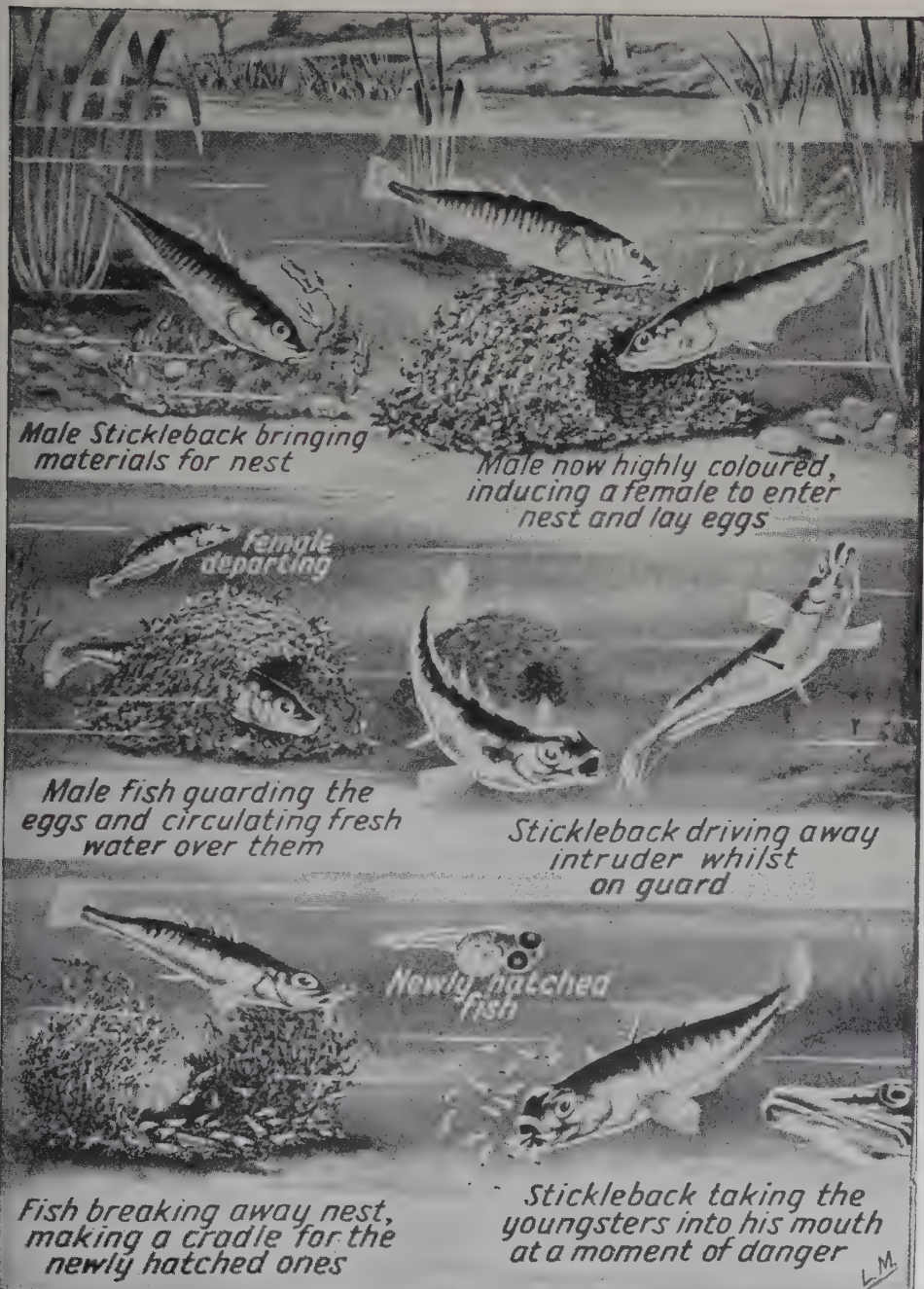


Fig. 17. The Stickleback, "Jack Sharp" or "tiddler," is one of the fishes that make nests. The male guards the nest like a nursemaid seeing that none of the youngsters are gobbled up

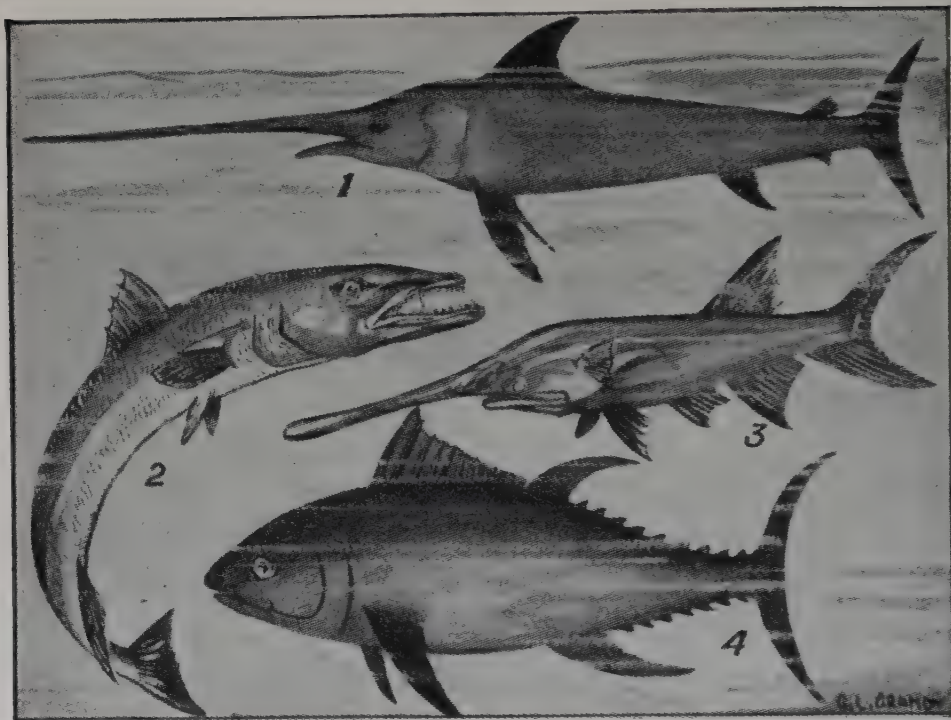


Fig. 18. Some huge fishes: (1) Sword fish, (2) Barracuda, (3) Spoon-beaked Sturgeon, (4) Tunny or Tuna

jet black stripes. The various varieties of goldfish are domesticated forms of a wild, dull-colored species. This fish is imported from Asia. Young goldfish hatch grayish-black, like their wild ancestors. As they grow, they gradually acquire the golden color that makes them so attractive. A number of goldfish introduced to the waters of Siam soon reverted to their ancestral form. On the other hand, in the "shubunkin" varieties, modern fanciers have developed a blue-tinted goldfish.

As with the birds and beasts, so with the fish. Man has upset the natural distribution by bringing Asiatic carp to British waters and taking British salmon to Australia and New

Zealand, and American black bass to South Africa. The rainbow trout have been sent from Yellowstone Park all over the world.

In Germany and at Plymouth, England, experiments have been carried out to train fish. The fish were found to respond to the note of a tuning fork sounded in lower C, and to proceed to a regular spot for their food. Wrasses were found to be able to discriminate between monochromatic—red, green, yellow, and violet—lights. The fish were attracted by an electric buzzer sounding a note F in the second octave, or by a tuning fork sounding lower C. To test their powers of discrimination further, discs, squares, triangles, and letters of the

alphabet were used. Thus we see that the study of the unsolved mysteries of fish life is today a good deal more than what Dr. Johnson likened to "a line with a worm at one end and a fool at the other!"

LUNGFISHES

Most interesting of all fishes in the study of evolution are the lungfishes, for they represent a stage in the transformation of gill-breathing fishes into lung-breathing creatures such as frogs and salamanders. The latter are known as *Amphibia* (*amphi*=double; *bios*=life) because they breathe in early life with gills, later, when they leave the water to crawl or hop over the land, with lungs.

The lungfishes do the same thing. They are eel-shaped, with a flat tail fringed above and below with a membrane, much like a frog's tadpole. In early life, the South American kind, called *lepidosiren* (meaning scaly salamander), has large, branching external gills much like those of an ordinary tadpole. Within a month



New York Aquarium

Fig. 20. This is the African lungfish. Unlike his Australian first cousin, he has fine delicate scales and slender fins. Here the lungfish seems to be resting on his fins, but he does not do so

these gills become very small, and then the *lepidosiren* breathes mostly with a pair of lungs developed below its gullet, as in a frog or in human beings.

There are two main kinds of lungfishes; which, however, have similar habits. Those of Australia (shown in Fig. 19) have large, rounded scales and broad, flat pectoral and pelvic

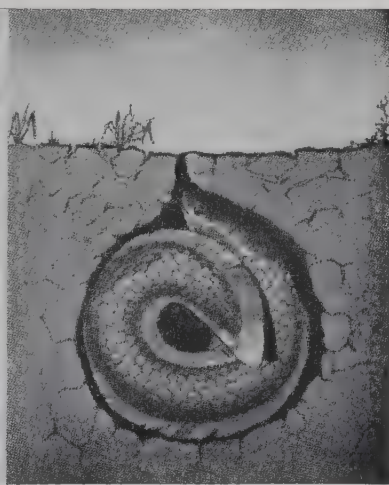


Fig. 19. The lungfish at normal seasons (left) swims about, but when the water dries up it makes a nest (right) in the mud and remains there, breathing through a hole

fins. Those of South America (*Lepidosiren*) and of Africa (*Protopterus* = "first fin") have delicate scales in a soft, froglike skin and slender paired fins. Their teeth are two pairs of broad, enameled plates with sharp edges. Curiously enough, fossil teeth of the Australian type (*Cerrotodus*) from Colorado were described by Agassiz in 1838 and others have been found in Europe and India, showing the world-wide distribution of lung-fishes in remote antiquity.

Their nostrils are not just shallow pits, as in other fishes, but open into the throat as in the frog and in man, but there are valves to keep out the mud. They breathe mostly through the mouth.

The lepidosiren of the Gran Chaco swamps of northern Argentina eats water plants voraciously, and becomes very fat. The water then is from two to four feet deep. But when the southern winter or dry season comes on (June, July), the swamps dry up and the lepidosiren burrows into the mud. As in the Australian species shown in the figure, it leaves a small breathing hole at the top of its burrow, closed only with a lid of mud, and breathes through its mouth until the rainy season arrives.

AMPHIBIANS

Amphibians—the frogs, toads, newts, and salamanders—are a link between fishes, particularly lung-fishes, and reptiles. From the latter they differ widely in their life history, for amphibians come from a relatively small aquatic egg, pass through a fishlike larval, or tadpole, stage, in which they breathe with gills, to a terrestrial adult stage with well-developed lungs. Reptiles, on the other hand, lay large eggs like

those of birds and are from the start lung-breathing, usually terrestrial, creatures. Amphibia also have soft, naked skins, quite unlike the reptiles.

The life history of the common frog is typical of that of any amphibian, although there are some tree frogs (living in an island of the Leeward group) which hatch their eggs on the damp floor of the forest directly into the adult frog without any tadpole stage. This stage is rushed through inside the egg, for these frogs dwell in the trees, their only water-swift mountain streams, for there are no forest pools there—being unsuitable for breeding, hence this strange adaptation to their peculiar environment.

In the case of our frogs, the spawn (Fig. 21) is laid in the ponds and brooks in early spring, and the gelatinous cover swells into large jelly-like balls. These are distasteful to fish and thus protect the eggs from enemies. The young tadpole, upon hatching from the black embryo of the egg, feeds on the jelly. It develops a head and tail and a suctorial mouth until, having absorbed all the jelly, it clings by that mouth to the pond weeds. Here it feeds on minute organisms if it is not devoured by dragonfly larvae, water beetles, or other frogs.

Gradually, hind legs develop in the little tadpole, which swims by wriggling its tail. Then the frill-like pair of external gills, which were on each side of the neck, wane, internal gills having been formed. Each of these has a gill plate, or operculum, covering them, as in fishes, for the tadpole is, as it were, a little fish without side fins. Then the tail shortens and loses its fin, the front legs push through the gill plates that have hidden their early growth, and the little frog becomes terrestrial. This metamorphosis



Fig. 21. Jellylike frog-spawn. The black dot in the center of each jelly cell is an embryo

takes about three months in the leopard frog, only two months in the toad. The bullfrog tadpole, however, waits until the following summer before changing into a froglet.

The frog spends the winter hibernating in land recesses and holes, returning to the water the following spring. They do not spawn, however, until they reach the age of two or thereabouts.

The adult frog can live in water, of course, but it spends most of its time in the nearby damp vegetation. If we look at a frog we see how it has three methods of respiration. Its throat seems to be constantly pulsating, but actually this is the floor of the mouth pumping air in and out of the nostrils, for the moist lining of the mouth is covered with blood vessels and acts as the main means

of respiration. Occasionally the frog takes a deeper breath and uses its lungs. The third method of respiration is by means of its moist skin.

There are three main orders of recent or living Amphibia, which include various sub-orders, or families, as follows:

LEGLESS, WORMLIKE CAECILIANS: These are a kind of primitive salamander so much like ordinary earthworms from the shape of the jointed body that you would have to examine the head and find the rather large mouth and small eyes to make sure they are real vertebrates and not just worms. They are found in the tropics throughout the world but nowhere in the United States. *Ichthyophis* is about a foot long and is found in India. It lays a cluster of large eggs,

strung together as on a cord, in a moist hole close to the water, into which the young escape as soon as they lose their large external gills. The eel-like young one, after losing even its internal gills, crawls into the mud, to live like an earthworm the rest of its life.

THE TAILED AMPHIBIANS, OR SALAMANDERS IN GENERAL: Since most of them stay in the water the most of their lives, they find their broad, flat tail extremely useful in swimming. They never outgrow these tails, though in terrestrial adults the form changes from flat to cylindrical.

There are four main groups:

Hellbenders and other giant salamanders
Salamanders proper and newts
Permanent - gill salamanders, mud puppy, and Proteus
Sirens

The hellbender is our largest salamander, about a foot and a half long. It is found in rivers and creeks in the eastern states from western New York and Pennsylvania westward to the Mississippi and further south. It is an ugly looking, squatty, thick-set creature, with loose skin like a rhinoc-



Fig. 22. The newts are a group of tailed amphibians closely resembling frogs in many of their characteristics, but they do not lose their tails nor do they have such large hind legs. They swim with their tails instead of their legs

eros, except that it is soft and full of blood vessels useful in breathing. It has temporary external gills, like a tadpole, and gill covers develop on the sides of its throat, which are a sham, for internal gills never develop and the gill covers close up, except at the upper edge. There are lungs, but the hellbender makes little use of them; he waves the fringes of skin along his sides in the process of skin-breathing. He makes a bowl-shaped depression in the river bottom in which the female lays strings of eggs. Then he drives her away and stands guard over them. Neither he nor she ever leaves the water.

Salamanders proper is a motley assemblage of different families. The most remarkable, and most unlike the others, is the *Ambystoma*, which includes the Mexican axolotls. Unless these axolotls are fed with a special thyroid gland extract, or have their water supply reduced, they do not normally complete their full metamorphosis to adult stage. They retain their external gills and aquatic habits, breeding thus and producing more axolotls. For this they are very popular pets with the aquarists. The axolotl is thus usually in a permanent larval form. On the rare occasions when it does reach the terrestrial, lung-breathing, adult form, it is a large-headed salamander, with short, stout limbs, a broad, blunt muzzle, and a shining, dark-brown skin with yellow blotches; it is then known as *Ambystoma mexicanum*, very like, if not identical with, the tiger salamander of our southwestern states.

The tiger salamander is about eight inches long. A slightly smaller species of the eastern and central states is the spotted salamander, which often turns up in the woods, and even

near houses, under logs and stones. In early spring these salamanders migrate by night into the ponds. The males deposit translucent sperm packets on solid objects under water, each packet containing thousands of sperm cells; these the female takes up into her cloaca, through which the eggs pass out, already fertilized. They are each covered with jelly and massed into a lump. In two or three weeks the tadpoles appear, having eaten their way out of the lump of jelly. Late in the fall their gills are absorbed, and their transformation from tadpole to a small adult salamander is completed.

The commonest salamander in most of the eastern states is the red-spotted newt, which in its adult stage lives in shallow ponds and quiet streams. They are about 4 inches long, including their flat tail; olive-green above, with a row of red spots along each side; yellow beneath, dotted with black. The male has a broader tail and thicker hind legs than the female. During the breeding season, the cloaca of the male protrudes and his hind legs acquire horny, black thickenings of the skin.

In breeding, there is a long preliminary clasping of the slender female by the male, but no transfer of spermatozoa occurs until they separate. Then, accompanied by the female, he deposits a white, globular sperm carrier upon the leaves of water plants. The gelatinous circular base and the "handle" of this affair support a "cup" which is a packet of spermatozoa. The female moves over the sperm carrier and receives the tiny mass of sperm into her cloaca. Her eggs are laid singly, each enveloped in jelly, upon the leaves of water plants.

The life history of this newt is very strange. The regular tadpole stage with broad, flat tail and external gills is followed, usually in the succeeding autumn, with loss of gills and tail. Lungs develop and the small salamander begins to come to the surface

their throats, partly by using their lungs. Hence they seldom come to the surface for air.

A surprising salamander with large, permanent gills is the mud puppy, or *necturus* ("tail swimmer"), common in many lakes and rivers of the north



Fig. 23. These repulsive little animals are salamanders. They are often kept as pets for they thrive well in fairly dry conditions

for air. Either before leaving the water or soon afterwards, its color gradually changes from green to red, and a small red salamander with cylindrical tail and terrestrial habits results. These "red lizards," as they are sometimes incorrectly called, are often found in wet places in the woods, creeping over fallen leaves or hiding under logs. Not yet sexually mature, they often live more than a year in this red stage.

Finally, either in autumn or early spring, they enter the water and within a few weeks are transformed into the green, sexually mature stage in which they breathe partly through the skin, partly through the lining of

central states. Its claim of relationship to the dachshund should not be taken too seriously. It is about a foot long, a little smaller and much trimmer than the hellbender. Neither of them ever leaves the water, but *necturus* remains throughout life only a puppy, for it never develops beyond the tadpole stage. Throughout life it retains its prominent, bushy red gills which constantly undulate as it breathes. It is brownish with blue-black blotches from which it gets its official name, *N. maculosus* ("spotted"). Active at night, it eats any sort of small animal which comes its way. The female glues her eggs to rocks, where they are guarded until they hatch.

A near relative in Europe is *Proteus*, the blind "Olm" of the caves of northern Yugoslavia and Austria. At Adelsberg, not far east of Trieste, according to Gadow in the *Cambridge Natural History*: "The river Poik, a moderate mountain stream, but a large, fierce torrent during the rainy season, disappears into the limestone hills, and rushes through enormous stalactite grottoes, most of which have only been partially explored, until several miles farther on it reappears at the surface. There, deep down below the surface, in absolute darkness, in an almost constant temperature of 50° F. is the home of *Proteus*."

It is white, with carmine-red feathery gills; kept several months in the light, it turns black. In length, about 10 inches, it resembles the mud puppy, but it is much slenderer, and has only three fingers and two toes on its tiny limbs; *necturus* has four. Its eyes are still visible in the newly-hatched young, about an inch long, but they quickly become covered with skin and useless. Lungs develop, and in poorly aerated water *Proteus* comes to the surface for air.

In the fourth class of the tailed amphibians are the sirens. It is not quite clear why these degenerate mud eels of our southern states should have received this high-sounding classical name. They have no striking resemblance to the sweet-singing half bird, half damsel of the ancient myth, though a mermaid idea may have been suggested by their having only one pair of legs situated just behind the head and joined to a long, smooth eel-like body and tail.

The mud eel, which, of course, is not an eel at all, burrows in the mud of ponds and ditches. It grows to a length of two and one-half feet. It

has three pairs of gill slits and four fingers on each hand. *Pseudobranchius*, a seven-inch species in Georgia and Florida, has only one pair of gill slits and three fingers.

JUMPERS: One of the most remarkable of all toads is the Surinam water toad, a tongueless toad of Guiana and Brazil. The female lays her eggs in the water, and at this time her soft back becomes much thickened. The male collects the eggs as soon as they are laid and embeds them one by one in the soft skin of the female's back. This soon closes over, so that each egg is protected in a separate cell, from which a young tadpole emerges 82 days later. The female may have as many as 120 such cells in her back, but 50 or 60 is the average. After the birth of her family, she rubs off the surplus skin from her back against plants and stones.

The midwife toad, or frog of Central Europe, is a disc-tongued frog. It lays its eggs in long chains from March to August. These chains, which may be a yard or more in length, are gathered by the male and wound round his legs and thighs until he can hardly move. He then retreats to some burrow or hole in the bank until the tadpoles are ready to hatch, when he returns to the water; the tadpoles swim away to take care of themselves.

The hermit spadefoot of eastern North America and the Gulf states is a burrower seldom seen except during the breeding season. It lives alone in a six-inch burrow. Only its prominent, projecting golden eyes, with their catlike, vertical pupils, appear at the door. The walls and bottom of the rounded burrow are packed down hard and smooth by the toad.

It is a rather smooth toad, a little smaller than the common American toad. It gets its name from a black, horny spur on the inner side of each webbed hind foot. Dislodged from its home, it begins at once to paw out another; and, if the ground is soft, sinks rapidly below the surface.

It appears in public only very briefly in the spring after a heavy rain. Then, for one night or two, hundreds appear in certain ponds or pools and make night hideous by their ear-piercing groans, "a deafening, agonizing roar, hoarse and woe-ful." Even an untuned saxophone in the hands of the worst player imaginable can scarcely compete on even

pletely disappear, and may not be heard in the same locality for many years. The eggs they have left in long strings, stretching out among the water weeds or grass, hatch within a fortnight; the tadpoles rapidly develop, leaving the water before their tails have been absorbed.

Two western species of spadefoot are not uncommon, one with smooth skin and pug-dog expression found in the northern plains (Montana, Dakota, Idaho, and Colorado), one with coarse tubercles on its back, found in California, Washington, Nevada, Utah, New Mexico, and Texas.

Toads differ from frogs in having a warty, instead of a smooth skin, and no teeth. Behind each eye and above the ear drum (which, as in the frog, is also on the surface of the body and behind the eye) is a large oval elevation which secretes an unpleasant juice when the toad is attacked. This gets its name from the well-known parotid salivary gland of the mouth, which, in man and the higher animals generally, secretes a digestive juice. It is inappropriately called the "parotoid" (parotid-like) gland. The warts of the skin produce a similar acrid secretion, but much less of it. Dogs learn to leave them alone. Red-tailed and red-shouldered hawks eat them but a Cooper's hawk, not accustomed to such a wide variety of foods, is known to have been killed by swallowing them. The secretion, however, is not poisonous to our skin and never produces warts. The toad has a dry (not slimy) skin; when handled, it may incontinently empty its bladder but nothing worse.

Toads, as is well known, are less active than frogs, less inclined to jump and more to creep. Except in early spring, they are strictly terrestrial in



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Fig. 24. The Surinam toad. The male of this species distributes the newly-laid eggs over the back of the female

terms with the hermit spadefoot. Huge, inflated air sacs connected with its throat serve as resonators.

Their performance of one night (or at most two nights) over, they com-

their habits and are a welcome and useful assistant to every gardener.

Toads live many years. One is known on good authority to have died by accident at the age of 36. They shed their skin over the head in one piece, every few weeks when rapidly growing, and swallow it. Tucking it into the big mouth and gulping helps a great deal in stripping it off.

The tongue in ordinary toads and frogs is attached in front, free behind. The free end can be protruded about two inches from the mouth and immediately snapped back with extraordinary rapidity. So the toad, squatting quietly, catches any small insect on the sticky surface and flashes it back into its mouth. The insect has disappeared; the body of the toad has not moved.

The American toad, which lives east of the Rocky Mountains from Mexico northward to the Arctic Circle comes out of its winter burrow in April in most localities and migrates in great numbers of neighboring ponds, where all through May at night one hears the musical chorus of its long, trilling song, which swells out in waves, as more and more singers chime in, or fades into momentary silence.

The eggs are laid in two long strings of jelly (one from each oviduct) with a single row of black eggs in each row. Development of the tadpoles is very rapid, so that early in July vast numbers of tiny black toadlets, which already have developed lungs and absorbed into their bodies the tadpole tails, are met migrating away from the pond. In the grass they are seldom seen, but when the army crosses a road hundreds or thousands are in evidence. Often it is next to impossible not to step on some of them, and their mortality is of course enormous.

In the Atlantic states, from Massachusetts southward, lives also the brightly spotted, less warty, more agile Fowler's toad. It stands cold weather with more difficulty than the



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Fig. 25. The adhesive discs on the digits of this giant tree toad make him well adapted to arboreal life

widely distributed American toad and gets into the water to lay its eggs two or three weeks later. The males have been found to outnumber the females: ten to one; they can be distinguished by their black throats. Their trill, heard chiefly in June and July, is a loud, harsh, wierd metallic drone, short and running down the scale.

One of the most curious toads is the narrow-mouthed toad of the southern states. It has a tiny head with small, beadlike eyes, but has a relatively large, squat body. Its skin is apparently too large, and folds up loosely

back of the head. It is nocturnal, rarely seen; its call note is said to suggest an electric buzzer.

Tree toads are so much half-way between toads and frogs that either name fits some of them. The tiny cricket frog, however, which is one of them, would hardly pass for a toad. It is a high jumper, only an inch long at most, and it is decidedly froglike in habits, for it lives among the weeds and meadow grasses along the borders of a pond. Its miniature toe pads are useful for sticking to grasses and not for tree climbing.

That is not true, however, of the tree toad (or frog) *Hyla versicolor* which has well-formed suckers on the tips of its toes and which changes its color automatically from gray to green or brown to match the bark of the tree on which it rests. It seldom is as much as two inches long; a smaller species, the spring peeper, another *Hyla*, is about half its size. Both of them are loud vocalists, much louder than one would expect from their size, thanks to the air sacs under the throat which swell out as they sing; the larger species makes an alto trill, the smaller a very high soprano, much repeated peep. The spring peeper is the earlier of the two in going to the pools to breed.

There are 15 species of tree frogs in North America. *H. regilla*, the Pacific tree frog, is a small, lively species with habits like the spring peeper. It has a loud, harsh, low-pitched cry which has been compared to that of a mechanical toy. In beauty and versatility of color, however, it compares well with its eastern cousins, changing from green and brown to almost black.

Somewhat like the tree frogs is Darwin's frog of Chile, in which the

throat sacs of the male are used as a broad pouch in which the eggs and tadpoles develop, nourished only by the abundant yolk stored up in the few large eggs.

True frogs are the water-loving jumpers described in introducing the Amphibia. American species belong to the genus *Rana* of which there are about 17 North American species. Their skins are smooth and, like the tree frogs, they have teeth on their upper jaws, which, with their protrusible tongues moored in front, loose behind, are excellent fly traps.

The big bullfrog is the largest North American frog and may reach eight inches in length. The name refers to his deep bass voice, rather than to sex. The females are even larger than the males, as is usual in frogs. She has a smaller eardrum than he and is often mottled with brown, while his color is plain green. This species occurs everywhere east of the Rocky Mountains.

The most common American frog everywhere east of the Sierra Nevada Mountains is the leopard frog which is easily recognized by the round, blackish spots rimmed with white. In the eastern states lives the spotted pickerel frog with nearly square dark spots and orange belly and legs. Its strong odor makes it bait for pickerel.

The green frog looks much like a small bullfrog but can quickly be identified by a prominent fold of skin running backward from the eye along the side of its back, which the bullfrog does not have.

The delicate little brown frog with a blackish band back of the eye and around the eardrum is the wood frog, which spends most of its time out of the water in moist woods, where it will easily be found after a rain.

One of the most interesting groups of foreign amphibians are the so-called flying frogs of some of the East Indian islands, in which the fingers as well as the toes are webbed and are said to serve as parachutes as the frog leaps from tree to tree.

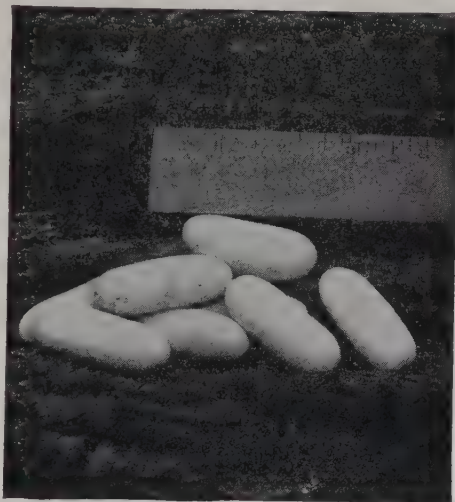
REPTILES

The reptiles, unlike their naked-skinned allies, the amphibians, from which they have probably ascended the evolutionary ladder, are scale-covered creatures which have definitely taken to a life on land. At least, none of them pass through an aquatic gill-breathing stage; their lungs are in good working order when they hatch from the egg, which their mother laid somewhere on the land, even in the case of those, such as the alligator and turtle, which spend most of their time in the water.

Knowing these facts, we should never confuse, as people often do, the naked-skinned amphibious newt and salamander, which are aquatic gill-breathers in early life, with the scaly, lung-breathing lizards which seldom go near the water and are 100 per cent reptilian. The lizard, to be sure, is shaped much like a newt or other salamander. It has the same kind of short legs and toes on a long, cylindrical body with a long tail. Like its amphibian (or still earlier fishlike) ancestors, it has the habit of relying on its tail for propulsion and limbs for balance. When in a hurry, a lizard obtains most of its speed by swinging its tail from side to side, merely using its legs to support its body.

Practically all reptiles lay eggs in soft, leathery shells, and these are hatched by natural heat. Sand lizards and turtles bury their eggs in the sun-baked sands. Similarly, in temperate

climes, adders bury them in manure heaps where warmth is generated. A few reptiles are viviparous, and either give birth to living progeny, or they hatch from eggs a few minutes after the female has laid them (Fig. 26).



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Fig. 26. These blacksnake eggs approximate two inches in length. The snakes are hatched shortly after the eggs are laid

The most extensive development of reptiles was in the long Mesozoic era when enormous dinosaurs dominated the earth and whalelike ichthyosaurs the sea. "Living fossils," or isolated survivors of those reptilian giants of the past, still linger in the world today. They are to be seen in the giant marine iguana lizards of the Galapagos Islands off Ecuador, the giant komodo dragons of the East Indies and the curious tuatera lizard of New Zealand, with its vestige of a third eye (Fig. 32). These ancient forms survive because they inhabit land isolated from the mainland and free from its dangers, such as predatory flesh-eaters.

In those same middle ages of the earth's history, when reptiles were predominant, experiments in flying were undertaken by certain members of this group, among which were the ancestors of birds, described in the following chapter.

Orders of reptiles now living are four:

- Turtles and tortoises
- Crocodiles and alligators
- Beak heads (Rhynchocephalia)
- Lizards and snakes

TURTLES AND TORTOISES: So far as turtles and tortoises are concerned, we might begin by correcting the common belief that "tortoise shell" has something to do with tortoises. In the larger sense, of course, it has, but strictly speaking it is obtained from the hawksbill turtle, a creature that has no other human uses, not even being suitable for soup, as is the green turtle. The beautifully mottled plates of its horny "shell," or carapace, take a high polish and are used for many purposes. At one time the shell was

obtained by steaming the animal until the plates came away, when the creature was released to grow a second set, but compared to the first, a vastly inferior one.

All chelonians, as tortoises and turtles are scientifically called, have a more or less fully developed bony shell or carapace. Their skulls resemble those of the crocodiles more than those of any other group of reptiles.

The largest of all the tortoises is the Atlas tortoise of the Siwalik Hills of Northern India. It reaches a length of six feet and, as in the case of the giant tortoises from the Seychelles and Galapagos Islands, is believed to live for over a century—sometimes for perhaps 200 or 300 years. The carnivorous water tortoises, or terrapins, have flatter shells. The curious big-headed tortoise of South China, Siam, and Burma, is a most grotesque creature that looks exactly as if it had been run over, so causing its shell to be flattened and its head to bulge to enormous size.

Another curiosity is the matamata tortoise of Brazil. It belongs to a group called the side-necked tortoise, and instead of having the usual horny, parrotlike beak, it has a nose that is a curious proboscis. Its neck is frilled with little fimbriated projections, and the horny shields of its carapace stand up like tiny mountains on a relief map. The snake-necked tortoise of the same country is named from its habit of withdrawing its head into its shell by placing it sideways instead of following the S curve of the other tortoises.

Turtles differ from water tortoises in having their limbs developed into swimming paddles, and they rarely come ashore except to lay their eggs.



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Fig. 27. Some idea of the size of the giant Galapagos tortoise may be gained by comparing him with the small species of Galapagos tortoise on his back. The big fellow weighs about 350 pounds

We are so used to seeing "mud turtles" of various kinds in our ponds and rivers that we hardly realize what primitive creatures they are. Imagine that we were looking at one of them for the first time, this flat, squatty, armored representative of the Mesozoic looking almost more like a beetle than a vertebrate. But, thanks to the security afforded by the coat of mail, sharp jaws, the conservative habits of some of them, and the vicious aggressiveness of those whose armor is too small (snapping turtle) or too weak (soft-shelled turtles), they have come through from the Mesozoic in full force.

They have held their own especially in the "new world" where there are more known species than in the eastern hemisphere. Of the 224 species in all, the western hemisphere has the majority; and, although they prefer warm and tropical climates and do not thrive in the far north, there are 55 species in North America.

Unlike fishes and amphibians, which have practically no necks, the turtles have long flexible ones, and, of course, they need them. In the South American snake-necked turtle the neck is slightly longer than the shell. The head, neck, legs, and tail of turtles are covered with scales. Sharp, horny ridges of the jaw take the place of teeth.

Over their ribs are spread flat bony plates sutured together and covered with horny shields. This armor of the back is the "carapace"; that covering the underside is the "plastron."

They all go ashore to lay their eggs, which are much like those of birds, in shallow excavations dug by the mother in sandy banks or beaches. The young have to look after themselves.



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Fig. 28. The hawksbill turtle, from which tortoise shell is obtained

The term "tortoise" is applied to terrestrial species, "turtle" to marine and certain fresh-water kinds, the snapping, musk, mud, and soft-shelled turtles. "Terrapins," large and small, are hard-shell, semiaquatic species. The larger ones are found along the seacoast in brackish or salt water, or in rivers, and are usually edible. The smaller include the common pond turtles and the wood or sculptured terrapin, which like the true tortoises lives mostly on land, though closely related to the spotted and painted pond turtles.

There are about six families of the whole group.

1. Leathery turtles
2. Sea turtles
3. Snapping turtles
4. Musk and mud turtles
5. Freshwater turtles and terrapins and tortoises
6. Soft-shell turtles

1. The Leatherback is the hugest of all living turtles, with a carapace over six feet long and weighing over 700 pounds. It inhabits warm surface waters of the Atlantic, wandering

northward as far as Nova Scotia. With its long, strong flippers, especially the forelegs, it is a graceful swimmer. Its back is covered with a leathery hide saturated with oil. The Atlantic species goes ashore at the Tortugas, Bahamas, and the Brazilian coast to lay its eggs. A similar species occurs in warm regions of the Pacific.



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Fig. 29. The alligator turtle, a voracious turtle found in the Gulf States, is esteemed as a food delicacy

2. Sea turtles, though smaller than the rare leatherback are also giants. They have hard shells and large flippers, and are found swimming in the warmer surface waters of both the Atlantic and the Pacific. Three species are of especial interest: the loggerhead, with a large head, hooked beak and smooth shell; the green turtle, with smaller head; the hawksbill, with beak like the loggerhead but shields of the shell overlapping like shingles. The green turtle and loggerhead are often sold in the markets for food; the former, with its green fat, is the more highly esteemed. The shields of the hawksbill are easily separated from the bony carapace and are—as we noted at the outset—the tortoise shell of commerce which is being replaced by plastic substitutes.

3. The snapping turtles are ugly creatures found in rivers and ponds. Their quick action in snapping at their prey and their powerful jaws make them formidable flesh-eaters, not to be recommended as pets. The alligator snapping turtle of the Mississippi River and Gulf states has a shell two feet or more long and weighs a maximum of 140 pounds for some of the full-grown of the species.

4. The musk and mud turtles are all smaller, exclusively American, river and pond turtles.

5. There are numerous freshwater and brackish-water American terrapins, the largest of which are edible. The box turtles, of which there are nine North American species, have a hinge across the plastron, so that the shell can be completely closed and the owner well protected from its enemies.

The tortoises are vegetarian, dry-land, amiable creatures. The giant tortoises of the Galapagos Islands, some of which weigh 300 pounds, are becoming nearly extinct. Many have been slaughtered for "sport" or carried away to zoos and museums. Six species occur in these tropical islands, 700 miles west of Ecuador.

6. Soft-shelled turtles swimming in the rivers of the southern states have webbed feet, long necks, and leathery shells. They are active and vicious, with sharp-edged jaws and a prominent tubular snout.

CROCODILES AND ALLIGATORS: In the Tropics, there are some descendants of the ancient mighty reptiles. These range from the ancient tuatera, or beaked lizard of New Zealand, to the crocodiles and alligators. Let us consider briefly some of these marvelous and surprising reptiles.

The huge, sluggish, crocodiles and alligators which so forcibly recall the pictures of the giant saurians of the past, are not so closely related to the common lizards as their shape might lead us to suppose. Quadrangular, horny shields form an armor on their backs, and their toes are more or less webbed. Their hearts differ from those of all other reptiles in having four chambers, indicating a higher form of development similar to that of birds.

Because its windpipe grows upwards to the nasal passage and has a bony palate shielding it from the remainder of the mouth, a crocodile can lie on the surface and breathe air, although its mouth remains below the surface and is actually full of water. The eyes, too, are raised so that the creature can scan the water surface while remaining safely hidden from view below. Except for an Indian species found floating some distance from land, these creatures are usually found in the world's greatest rivers and in their estuaries.

Crocodiles are excellent swimmers, but very awkward on land, for which reason they seldom wander far from water. All are carnivorous and largely nocturnal in their habits, feeding on fish and small game. Because their gullet is so small, they are compelled to mangle and rip up their prey before swallowing.

Crocodiles and alligators lay from twenty to sixty white, gooselike eggs (Fig. 30). Having buried these in the sand, the female leaves them to hatch, sleeping on the summit of the nest. When the young are ready to hatch, they cry in a way similar to that of a baby bird that can be heard peeping before the eggs hatch. Then the parent digs down to allow them a free

passage through the sand, and the young crocodile perforates the shell (Fig. 30). It does this by the aid of a specially developed horny scale at the tip of the upper jaw, similar to the egg tooth developed on a chick in the shell. A crocodile's egg takes about ninety days to hatch, and the young crocodiles grow at the rate of about one foot a year for the first few years, more slowly thereafter.

The sacred mugger crocodile in the pool at Manghophur, near Karachi, is reputed to be over 100 years old. He is so old that he has lost most of his teeth, and is too feeble to fight for his food. He has to be fed artificially. Many of these mugger croco-

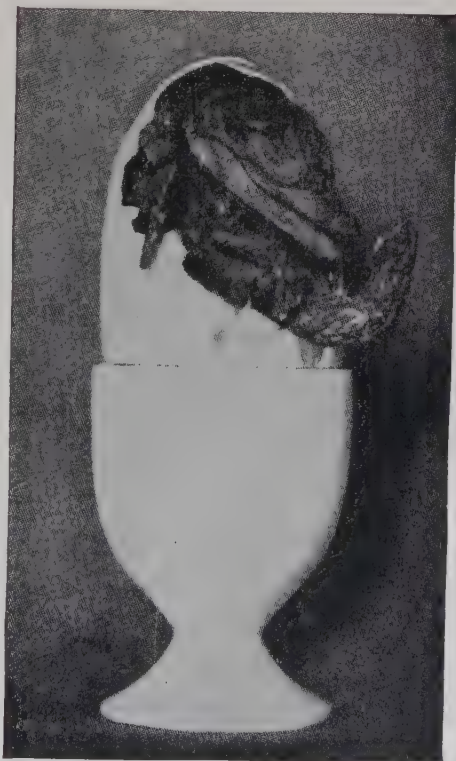
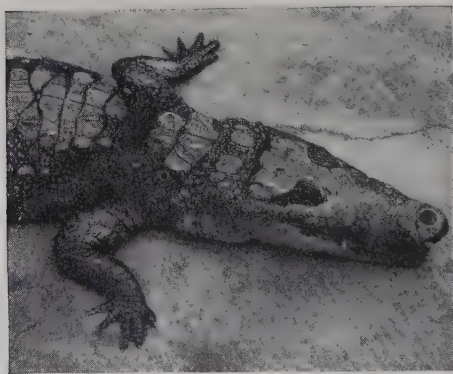


Fig. 30. An alligator breaking out of its egg after a period of about ninety days

diles in India are objects of religious veneration.

Crocodiles in the widest sense include four groups, or genera, distinguished from each other by the shape of the head and snout. Arranged according to the sharpness vs. bluntness of the snout, *Gavialis* of India comes first. These huge inhabitants of the Ganges, with snouts, as Dr. Ditmars says, "like the handle of a frying pan," are said to reach a length of 30 feet, exceeded by no other member of this "family."

Next in order come the members of the genus *Crocodylus*, then the South American *Caiman* and, finally, the blunt-nose *Alligator*. The common alligator of our southern rivers has a broad, flat, blunt head, rectangular in its general outline or shape.



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Fig. 31. The Nile crocodile. A species of plover may often be seen picking this crocodile's teeth for him as he lies basking in the sun

The American crocodile has a triangular, pointed head. It lives in the rivers of Ecuador and northward into Mexico, in the West Indies, and at the southern tip of Florida. It is of about the same length (14 feet) as the alligator (16 feet max.) but much more

slender, active, and vicious. In color it is olive or gray, rather than blue-black like the alligator. Young ones are greenish.

The Cuban crocodile, not over eight feet long, is similarly active and vicious. With the help of its tail, it makes high jumps from the water. The really dangerous man-eaters are the African *Crocodylus niloticus* (or the cuss which inhabits the Nile) and the salt-water crocodile of India, North Australia, and the whole Malay region between the Solomon Islands and Indo-China. This formidable creature, *Crocodylus porosus*, reaching a length of 20 feet will often swim far out of sight of land.

Five species of *Caiman* are found in Central and South America. The largest of them is the 20-foot black caiman of the upper Amazon, the hugest member of the crocodile family in the Americas.

BEAK-HEADS (RHYNCHOCEPHALIA): In Mesozoic times, a group of lizardlike beak heads flourished in various parts of the eastern hemisphere. The middle of the upper jaw was toothless and bent down like a beak over the lower. Only one representative survives, found only in New Zealand and threatened with complete extinction. It is *Sphenodon*, or *Hatteria*, called by the natives, the tuatara. About 2 feet long, nocturnal in habits, inhabiting holes which they dig and share with petrels, they often lie in the water, remaining below the surface for hours.

About 10 white, hard-shelled eggs are laid in the sand. The median, parietal eye in the roof of the skull is well developed, though lost or converted into a gland in most vertebrates.

LIZARDS: Although the reptiles of today do not attain the prodigious size of some of their predecessors in the Mesozoic era, so-called "Age of Reptiles," the lizards have successfully adapted themselves to a multitude of very different surroundings, assuming a corresponding number of different forms. In all probability the Age of Reptiles was a hot time and moist, where the ancient saurians thrived, supporting a rank growth of vegetation, upon which all animal life ultimately depends. So today, the lizards flourish best in the tropics, less well in temperate zones and not at all in the frigid extreme north and south, into which the warm-blooded birds and mammals have penetrated.

Lizards never attain the huge size of crocodiles, but the monitors of the

East Indian jungles reach a length of eight or ten feet and are powerful flesh eaters. Some are ground lizards, running with almost incredible speed; many inhabit trees and some fly, or rather make long, gliding jumps; the ancestors of not a few lost their legs in ages past and have become snake-like or blind dwellers in the soil, looking strikingly like earthworms.

Only a few of these changes rung by evolutionary processes can be mentioned here. The geckos are the "house-lizards" of tropical countries where they are in some places welcome tenants of native houses. Their feet have a sucking disc under each toe by which they stick to the walls and ceilings of houses, or to trunks of trees. Active at night, they capture multitudes of insects. Some species

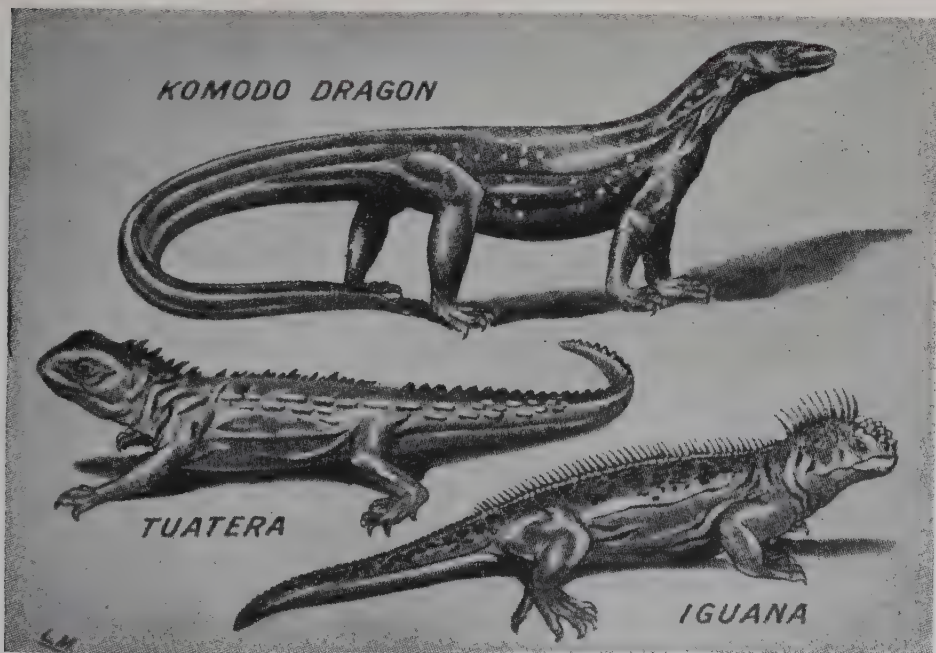


Fig. 32. Three remarkable remains of the Triassic age. The tuatera comes from New Zealand, the komodo dragon from the East Indies, and the iguana from the Galapagos

are noisy and make a clicking call—"gek-ko." The banded gecko of Texas and the southwestern states, striped yellow and black, a small species only three inches long, has acquired the unjustified reputation of being poison-



Fig. 33. The bearded lizard of Australia has an array of spiny scales under its throat running all the way around to its ears on either side of its head

ous. Its aggressive manner and "warning colors" explain why it is looked on with suspicion.

Only one lizard is poisonous. This is the Arizona *Heloderma* or Gila monster, the poison of which is situated in glands near the roots of the teeth. This is a bulky two-foot, pink-and-black reptile with a broad, stumpy tail. It makes sure of the effect of its poison by hanging on to its victim with bulldog tenacity. *Heloderma* stores a food reserve of fat in its tail—in which it is similar to the fat-tailed sheep—as a reserve against times of scarcity.

Conspicuous among the American lizards are the huge iguanas, some of which are six feet in length. Large flocks of the marine iguana have been seen running over the ramparts at San Juan, Puerto Rico. Some of them are four and one-half feet long. They have a flat tail used to great advan-

tage in swimming. A crest of spines runs along the whole length of the back.

The crest of the common Central and South American iguana is soft and leathery. This is a big fellow, reaching a length of six feet. Largely vegetarian, insects, mice, young rats, and birds are also eaten. These iguanas are sometimes on sale in New York markets and taste like chicken.

Small green lizards, genus *Anolis*, of southeastern United States and of Cuba are often kept as pets, sold as "chameleons." Dull brown while resting in the direct sunlight, the body color changes rapidly to gray or vivid green as changes in light, temperature, or excitement affect it.

The horned lizards or "horned toads" of the Southwest and Mexico,



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Fig. 34. The Central American iguana attains a length of almost five feet. It is timid in spite of its fierce appearance

often kept as pets, are strangely modified representatives of the iguana family adapted to desert life. Their flat, brownish-gray bodies, with prominent spines on the head and short tail, somewhat suggest the toad, as does their extreme composure unless stimulated by the intense heat of their native desert. In two species Dr. Ditmars observed that under excitement a "jet of blood as fine as a hair shot from what appeared to be the corner of one of its eyes, striking a

The little flying dragons of Malay have elaborate crests and wattles. The large expansion of their ribs, which bear gaily-colored membranes, enables them to glide through the air from tree to tree. Even more marvelous are the frilled lizards of Australia. When excited they raise a colored ruff nearly 10 inches in diameter. At the same time their jaws open wide to display a saffron yellow mouth, the whole appearance being so awesome as to scare away any would-be enemy.



Fig. 35. The slowworm or blindworm is trebly misnamed. It is neither slow nor blind, nor yet is it a worm. Actually it is a legless lizard. The name was originally sla-worm

wall fully five feet away, where it was distributed in a shower of tiny drops."

The largest of all modern lizards are the Monitors of Asia and Africa, some adapted for desert life, others, such as the komodo dragon, or giant monitor, of the Dutch East Indies, with its powerful legs and laterally flattened tail, are excellent swimmers and at home in the jungle. Wild and fierce in attacking their prey, they become tame when well-fed in captivity, but an eight- to ten-foot dragon with a powerful lashing tail is a formidable opponent. They have been kept in zoos, however, with little difficulty.

More extraordinary are the various snakelike and wormlike lizards. Among them is the so-called "blind-worm" or "slowworm" (Fig. 35) of Europe which is very much misnamed. Although its appearance is that of a big, dark-brown worm with a bright eye, it is neither blind nor slow, nor is it even a worm. Actually, it is a legless lizard, the name having originated in sla-worm, or worm-slayer. This lizard is viviparous, giving birth to from 12 to 18 black-and-white young.

The American glass snake is iridescent white beneath and shiny dark



Fig. 36. The chameleon, with its wonderful power of accommodating its color to its surroundings, is another member of the lizard family. Chameleons live entirely on insects

brown and black above, variable in color but having a glassy, highly polished appearance. It shows clearly the extra median eye which in higher animals becomes the pineal gland.

The two-headed snake of Trinidad and South America (*Amphisbaena alba*) gets its popular name from the fact that the blunt tail looks so much like the head that it takes careful examination to tell them apart. The habit of raising up its tail when annoyed helps the illusion, which carries with it the belief that the lizard can crawl in either direction. It is a grayish, mottled, cylindrical creature reaching two feet in length.

Still more curious is the Florida worm lizard having the size, shape, and superficial jointed appearance of an earthworm. It burrows in the ground in long tunnels within which

it can move in either direction. Adaptation to life in the soil, as in the similar case of primitive amphibians found in India, involves transformation and degeneration of vertebrates into the make-up of simple invertebrates, showing the powerful effect of the environment in evolution.

Adaptation to tree life is seen in the true chameleons of Europe, with their opposable fingers and prehensile tail. The long tongue can be flashed far out of its mouth to catch a distant insect. Everyone knows of its wonderful power of altering the skin color. By changes in exposure of pigment-bearing cells under the influence of the surrounding light and its nervous system, it quickly harmonizes itself with the surroundings and expresses its emotions. The chameleon has the very remarkable faculty of being able

to direct one eye forward and the other backward, thus seeing both ways at the same time.

SERPENTS: The snake glides on its ribs. Its skeleton shows an enormous development of ribs along its body, while its original pair of lungs is reduced to one.

Except for traces of leg bones in the boas and pythons (Fig. 38), snakes have lost their limbs. If we look at a snake, we see that whereas the scales of its back are arranged in typical overlapping fashion, those of its belly are like the rungs of a ladder. That is, each scale is keeled to the edge of a rib and raised a little by movement through its ribs, which turn the scales and enable them to grip. The snake has its jaw bones joined by such elastic ligaments that it can swallow prey that is actually considerably larger than its mouth cavity. Not all snakes are poisonous, for many—like the boas—are constricting snakes. They twine their bodies around their victims and crush them to death. Some of the better known snakes are illustrated in Fig. 39 on the following page.

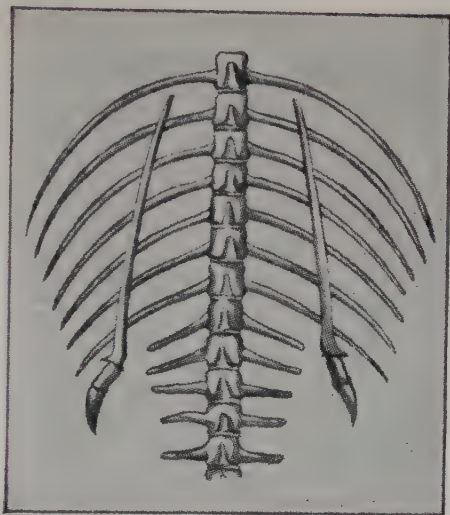


Fig. 38. Skeleton of a python showing rudimentary hind limbs (ventral surface)

Poisonous snakes do not sting, as many people imagine, nor do they use their forked tongue to harmful effect. Most of the older artists drew snakes' heads incorrectly, showing the mouth opened too wide. When we watch the snakes at the zoo, we can see that they slip the forked tongue between the lips and that the mouth is scarcely opened at all.

The dangerous snakes inflict their poison in a bite. The large fangs fold back along the mouth to drop down when the mouth is opened and the snake raises itself to strike (Fig. 37). These fangs are grooved, and when the snake strikes and bites its victim, it presses on the poison sac at the base of the

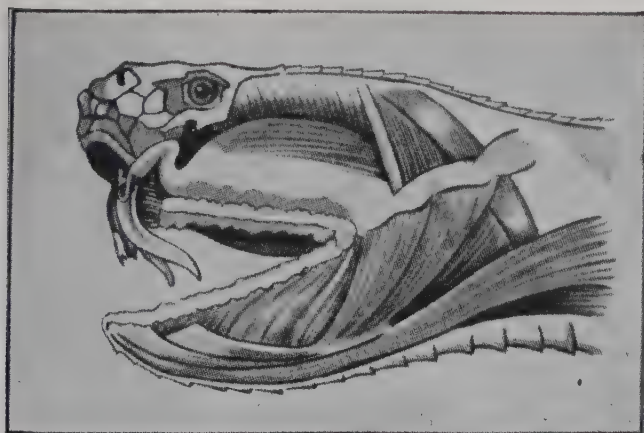


Fig. 37. Anatomy of snake's head showing curved fangs

fang, which is actually a modified salivary gland. This squeezes the poison down the groove and into the wound of the victim.

The king cobra, or hamadryad, of Malay—10 feet in length—is one of the largest and most poisonous of snakes. It rivals Russell's Viper of India in this respect, and it has the unenviable reputation of seldom hesitating to attack. Normally, it feeds on other snakes. The first king cobra at the London Zoo was placed overnight in a cage with four common cobras, and next morning it was found to have eaten them all—the cost of this meal was \$60. The puff adder of Africa is little less dangerous than Russell's Viper of India, and the bushmen use its poison on their arrows.

The dreaded rattlesnakes (Fig. 39) of America are also vipers with broad, triangular heads, short, thick bodies, and the famous jointed, horny appendages to their tails. In the baby rattlesnake this rattle resembles a terminal button, the various hollow, horny rings, which may attain twenty or more in number, being produced between this and the scaly tail. These rings consist of a quill-like substance, and are interlocked, and yet elastic enough to allow a considerable amount of motion between them and so to produce the curious rattling noise, from which the reptile derives its name. The use of the rattle is supposed by some people to be similar to that of the hood of the cobra, which is swollen before it attacks.

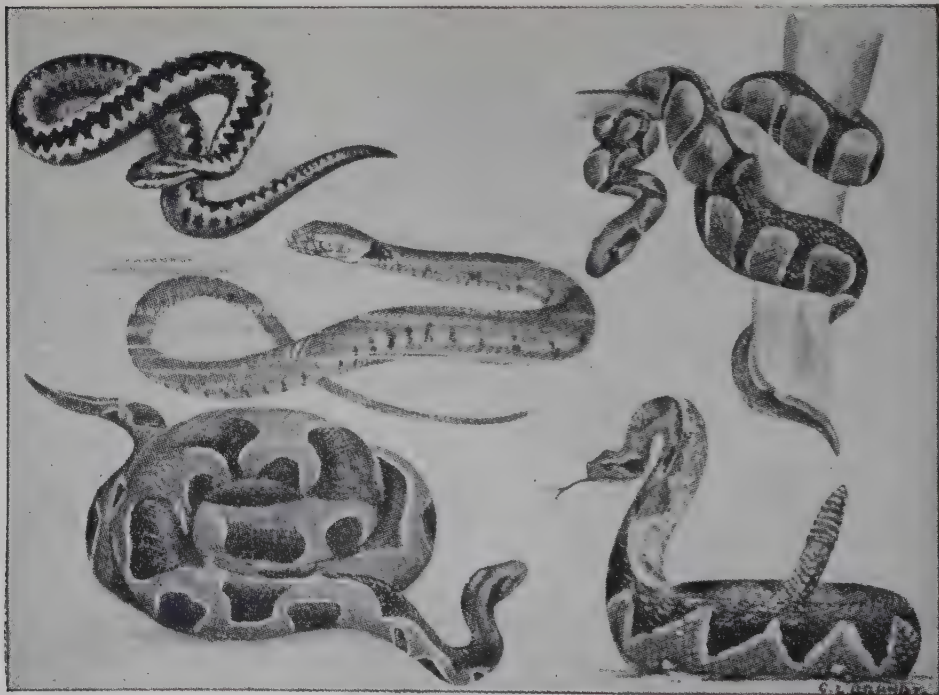


Fig. 39. Some of the better-known snakes: viper (top, left); grass snake (center); python (top, right); boa constrictor (bottom, left); rattlesnake (bottom, right). Note the differences in skin markings

These features have the same uses, according to this theory, as the hissing of snakes, that is, to terrorize victims into submission, or to warn off formidable foes.

It is an erroneous idea that snakes are useless and dangerous creatures, for only a minority are poisonous. That they are valuable in their own sphere is evident from the fact that the recent trade in snake skins for shoes and handbags has caused strong protests from the tropics against the extermination of valuable species that destroy rats, mice, and other vermin. Recent research at London and Rangoon Zoos has shown that, when diluted, the venom of the deadly Russell's Viper of India is effective in treating sufferers for haemophilia, that dread disease in which victims bleed to death through failure of the blood to clot.

Although the vipers include some of the most deadly snakes, they also serve their purpose in the economy of nature. Some years ago, when the Intendant of the Imperial Castle of Lazemburg in Lower Austria offered a bounty for all vipers killed in the neighborhood, over 1,000 were slaughtered in a single year. Experts pointed out the foolishness of this procedure, however, and to test their theory, one was dissected and was found to contain the remnants of over one hundred grasshoppers.

Most reptiles shed their old skins periodically. This is a good sign of health in a pet snake, for if not healthy it will have great difficulty in shedding its skin. Normally this is rubbed off backwards, taking with it a complete transparent horny covering of the scales and even of the eye.

There are true sea-snakes quite different from the oceanic "monsters" so

often described—the results, in nearly all cases, of imagination. They inhabit the coastal waters of India, and Australasia, but are strictly air-breathing, highly venomous, and dreaded by the pearl divers and fishermen in whose nets they may be caught. Their tails



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Fig. 40. The fer-de-lance, a savage member of the rattlesnake family, is a native of northeastern South America and of Mexico

are laterally flattened and oarlike. All are viviparous. Many are brilliantly colored. They feed on fish, and have been seen hunting in shoals in the Bay of Bengal. The black-banded sea snake, one of the most abundant found in Indian seas, grows to a length of six feet.

The yellow-bellied sea snake is found not only in the Indian Ocean and Malaysia but also in the eastern Pacific from Mexico southward along the coast of tropical South America. It is small, rarely as much as three feet long. Its black or deep-brown back is sharply marked off from its yellow belly; the flat, yellow tail is spotted or banded with black.

The adder, or viper, of Europe (Fig. 39), the only poisonous species in Great Britain, is a stumpy grayish-

brown serpent about 10 inches in length, with a zig-zag yellowish line down the back that forms a V on the head.

That there are no snakes in Ireland is in keeping with the legendary curse placed on them by St. Patrick. The absence of many other common British animals, and the lingering of a great race of giant fallow deer, is due, however, to longer and more complete isolation than Britain from the European mainland.

Snakes are by no means immune from foes. Wherever found, the hedgehog is an inveterate enemy of the viper, which it kills by nipping it behind the head to break its backbone. In Egypt the mongoose, a little, ferretlike mammal, is a great snake-killer, as is also the secretary bird of South Africa. In America the Cooper's hawk, great horned owl, and other birds of prey, take heavy toll of the snakes.

Classification of Snakes

To assist in arranging our ideas about some of the many kinds of

snakes, of which about 1600 species have been described, we will examine a list of some of the more common or interesting examples.

(1) Wormlike, burrowing blind snakes, some of which have the size and superficial appearance of earthworms.

(2) Boas and pythons. No fangs nor poison; all are constrictors, squeezing their prey to death. They have a pair of internal hind legs which in some species protrude as spurs. The Anaconda of South and Central America is 17 feet long, largest of American boas. The celebrated boa constrictor is smaller (11 feet or less). Pythons are mostly Old World inhabitants. The regal python of southeastern Asia and Malaysia reaches a length of 30 feet and weight of 225 pounds. Boas as a rule are viviparous; pythons lay eggs which they coil around and protect.

(3) Common snakes (Colubridae). An immense number of species in two groups, (a) non-poisonous, (b) poisonous.

(a) Includes the common garter snakes, striped, viviparous; water snakes, transversely banded, viviparous; black snake or racer (improperly described by its scientific name, "constrictor"), an egg layer; green snake, also oviparous; king snakes, oviparous, constrict and eat other snakes and small animals. The scarlet king snake is called "coral snake" from its resemblance in color to the venomous species to be mentioned below. The milk snake is a small, blotched king-snake relative said to "bewitch" cows and interfere with milk production. (b) Poisonous colubrids; sea snakes; cobras (*Naja*) and American representatives (*Micrurus*). The cobra of India, when disturbed, raises its head, spreads its neck into a "hood" marked



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Fig. 41. The garter snake produces many crawling progeny at one time. It is a viviparous snake

with glaring spots, and from this menacing position strikes vigorously. Thousands of people are killed by it every year.

In the United States, its nearest relative is the small harlequin snake,

one of the venomous "coral snakes." It is found in Florida, South Carolina, and Georgia, about three feet long, ringed with crimson, yellow, and black. Another brighter species is found in Arizona and New Mexico.

(4) Vipers (Venomous, with long fangs)	True Vipers (Old World)	{ European Viper Puff Adder
	Pit Vipers (Pit between eye and nostril)	{ Rattlers Copperhead Water Moccasin Fer-de-lance Bushmaster

CHAPTER 22

BIRDS

IF we should compare closely the development within the egg of birds and reptiles, and then follow it with a study of their grown-up anatomy, skeletons, hearts, brains, etc., as Thomas Huxley did long ago, we would have to admit that birds and reptiles have many points in common. They both lay relatively few large eggs with a huge amount of yolk on which the embryo subsists during its period of incubation by the brooding mother or by the sun's heat. The eggs of both are covered with a tough membrane and in birds, of course, with an additional calcareous shell.

Amphibians (batrachians) like frogs, toads, and salamanders, on the other hand, lay numerous eggs as small as buckshot, unprotected by anything like a shell but thickly covered with a mass of nutritious jelly on which the young tadpole feeds after absorbing the limited amount of yolk carried over from the egg. The tadpole of a frog, toad, or salamander is at first a fishlike gill-breather and then transforms into a more or less terrestrial, lung-breathing hopper.

Reptiles, on the other hand, whatever may be said against them, never lead a double life. Like chickens, the reptiles, such as lizards, turtles, and snakes, hatch from the egg, already able to trot about upon the land and breathe the air of heaven into well-formed lungs. It must be acknowledged that their mother, once she has planted her eggs in a sand bank or drops them in some sequestered spot, takes little thought of their future, but why should she, since they

are able with little or no help to shift for themselves?

We cannot here delve into the similarities between skeletons of a bird and a reptile; the successful modern reptile has a roomy skull lodging a brain generally big and efficient enough to give it some keenness and drive in hunting for food, a skull poised on a single pivot so that it can swing around to see what is going on behind it, helped in many cases by a long and flexible neck. Reptilelike scales upon the bird's legs show how it barely escapes being a reptile, its airy feathers representing scales so much transformed that no one but an inquisitive zoologist would suspect that both are of similar origin. To be sure, the reptile is cold-blooded, the bird warm-blooded, but recent studies on body temperatures of wrens have shown that the infant callow wren begins life like a reptile, with blood temperature "cold," i.e., corresponding to that of its surroundings. During early life it depends upon central heating of the nest by its mother's body until the feathers have grown and it is able to maintain a constant high temperature of its own.

Such similarities in development and bodily structure are all very well, you may say, but how about the differences between a bird of the air, "blithesome and cumberless," and a skulking reptile "trodden under foot of men"? What right has a zoologist to claim that both had a common origin and even go so far as to advance the theory that the first birds were reptilian?

THE ARCHAEOPTERYX

The answer to that is the archaeopteryx. This strange bird, the size of a crow, flew along the shores and over the swamps of Bavaria, during the Upper Jurassic era, the age of reptiles. That was the interesting eon when huge biped dinosaurs ("terrible lizard") stalked up and down the red sands of what is now the Connecticut valley at Turner's Falls, Massachusetts, leaving their three-toed foot prints on the sands of time, now sandstone. Some dinosaurs were no larger than a cat, others would tower above an elephant, measure upwards of forty feet from stem to stern, and rival a modern whale in bulk. There was little chance of one of them experimenting with aviation, though one may imagine from their build that

they might have jumped sometimes like kangaroos. But a cat-sized one (*Compsognathus*), about two and one-half feet long was found in the fine-grained limestone of the Solenhoven quarry at Eichstadt, Bavaria, in company with archaeopteryx.

Archaeopteryx itself could almost be classed as a delicate flying dinosaur. It was a feathered reptilian bird with a long, lizardlike tail fringed with plumes. It had jaws with teeth in them, and three claws projected from the front edge of its wings. A modern South American bird, the hoatzin, as a nestling, has similar wing claws, useful in tree climbing.

Clawed fingers likewise extended from the edge of the batlike wing of the pterodactyls, flying reptiles. These creatures, some of which flew over



Fig. 1. An artist's impression of the pterodactyls, flying reptiles

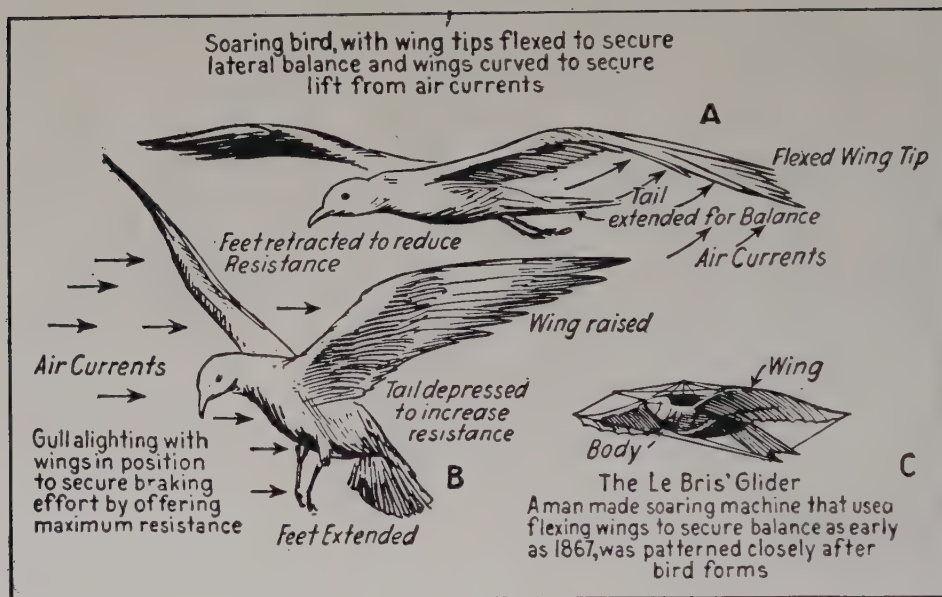


Figure taken from: Victor W. Pagé, ABC of Aviation.
Norman W. Henley Publishing Co.

Fig. 2. Soaring bird with wing tips flexed to secure lateral balance and wings curved to secure lift from air currents

the waters of what is now Kansas, varied in size from that of a sparrow to at least twice the size of the South American condor, which has a wing expanse of about 12 feet. Besides the three clawed fingers of the pterodactyl projecting from the front of the wing, their fourth digit (our "little finger") was enormously lengthened, forming the supporting framework of the membranous wing.

The fact that bones of these flying reptiles and reptilian birds are embedded in chalk (pterodactyls) and limestone (archeopteryx), along with marine fishes and shells, indicates that these ancient aviators ventured far out to sea.

It was the study of modern soaring birds which gave the first human aviators their clue to successful flying. Efforts like those of Lilienthal to in-

vent a flying machine with flapping wings unfortunately came to grief, but better success was achieved when gliders, patterned after soaring hawks and gulls and supplemented with gasoline engines were used.

A gull with outstretched wings, head reaching forward, tail extending backward, feet drawn in, combines a large supporting gliding surface with streamlined contours. Flexed wing tips give it lateral balance, and arched air-tight wings impinging upon underlying air currents buoy it up. The bird has two advantages over the airplane. Not only can it increase its momentum by flapping, combined with a forward thrust of its body, but it can, as Pagé says, "change its center of gravity in its relation to the center of pressure and secure up and down flight by movement of its head,

tail or wings." No such flexibility has been achieved by the airplane, though the driving power of modern engines gives a speed many times that of any bird.

STRUCTURE OF BIRDS

The striking thing about most modern birds is, of course, their equipment for aerial life. Naturally this involves wings covered with long, air-proof feathers and enormous breast muscles (white meat of the turkey) to flap them. With the breast muscles have developed special features of the bones to which they are attached: a large, boat-shaped breast bone with a deep keel, broad shoulder blades, and a pair of united collar bones forming the "wishbone." Moreover, some of their long bones are hollow, and air takes the place of fatty marrow. Membranous sacs, full of air and connected with the respiratory passages, give buoyancy to the body.

The skull, too, is very light, with its bones closely fused together and extended forward into the beak. In a few birds, e.g. parrots, the upper jaw is moveable and hinged to the skull, quite unlike other vertebrates (including man) in this respect. On each side of the skull are the deep, cuplike "orbits," in which roll the big eyeballs. The whole head rotates freely on a single knob, or condyle, playing upon the first backbone, or vertebra. Man, as well as most other mammals, has a pair of knobs, two "condyles," and so is not well equipped for looking backward, but our stereoscopic vision (both eyes in front acting in unison) largely makes up for that deficiency.

The absence of our type of vision is evident in the robin hopping across the lawn in search of worms; he cocks his head to one side to watch

for tips of worms protruding from their burrows. Each eye acts independently. The fibers of the optic nerves cross independently beneath the brain to join the opposite half of that important structure, as in fishes and reptiles. This lack of co-ordination between the eyes may have its advantages. While watching the worm with one eye, the other is on the lookout for approaching enemies and is extremely sensitive to any moving object.

SENSE OF SIGHT

Huge, far-sighted, keen eyes, with a brain having big optic lobes to go

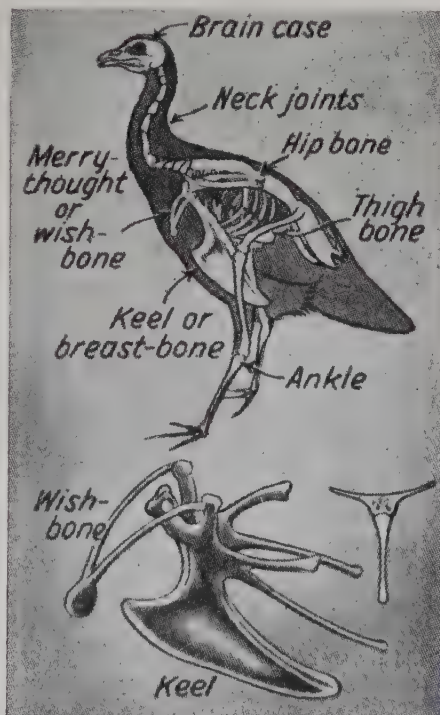


Fig. 3. (Top) Positions of fowl's principal bones. (Bottom, left) The keel, showing how the wishbone is attached. (Bottom, right) End-on view of keel, showing how thin it is

with them, are characteristic of birds. Their sense of smell is poor; taste probably not so bad. Their quick eyesight tells them at once whether a thing is good to eat, and their memory along that line seems to be excellent. Thus, credit is given to them by many students of butterflies, on the basis of their good sight and memory, for the evolution of unconscious mimics among insects, one of which is our orange-brown viceroy butterfly. This species, presumably palatable to birds (just as the blue-black species of its own genus are supposed to be), is said to have changed from blue-black to orange-brown during the course of evolution, because this newly evolved orange-brown coat "mimics" (or superficially matches) that of the "bad-tasting" monarch butterfly which roams widely over the earth north of the equator. Then, seeing a viceroy, and not realizing that he is regarded by entomologists as very good eating (for birds), hungry but keen-sighted birds quickly pass him by on account of his color. Hence those ancestors of the viceroy which happened to be more orange-brown than blue-black flourished, and raised well-protected, large families. Natural selection thus helped them become a new species, superficially unlike those really most like them, and superficially like the monarch butterfly, so well known and unpopular in bird circles. However, we have already discussed the theory of mimicry in its various aspects much more fully in the chapter on Insects and the reader is referred to it.

That hummingbirds have a keen eye for color is proved by their occasional blunders, their attempts to extract honey from lifelike colored figures of flowers on a woman's dress or

on paintings set out in the sunlight for their inspection.

The far sight of the eagle is proverbial. The hovering marsh hawk far up in the sky detects with its telescopic vision the motion of the minute field mouse. The osprey (fish hawk) dives hundreds of feet through the air to grab in its claws a fish disturbing the surface as it jumps at a fly. The condor, flying so far off that it seems only a speck in the sky, detects and wings its way toward the carcass of a dead animal, just as do our turkey buzzards.

Nowhere else than in birds do we find such instantaneous changes from far to near vision (or the reverse) due to contraction and expansion of the pupil (iris muscles) and lens adjustment (ciliary muscles).

FEATHERS AND FLIGHT

While flight can be accomplished without feathers, as proved by the old reptilian aviator, pterodactyl, and the mammalian practitioners of that art, the bats, it must be recognized that feathers contribute more to success in aviation (which means, as we are likely in these days to forget, simply bird-locomotion) than any other trait of this airy tribe.

Microscopic feathers, of course, usually unfairly called "scales," cover the wings of butterflies and moths, where they help buoy up the insect, as the flapping or gliding wings impinge upon the somewhat heavy air beneath them. Strip them off and the wings are deprived of the film of air which they envelop and which affords some friction against the air currents and some buoyancy.

Far more important are birds' feathers, not only for the supporting and steering qualities of the long feathers

of wings and tail but also as insulation against heat and cold. Air held among the two-shafted body feathers is an excellent non-conductor of heat and a surpassing protection against the force of the wind. Against the frigid temperatures of the upper air, the bird is further protected by its own blood heat which runs up to 110° or 112° F. in high flyers, even when they are at rest.

Perhaps you have wondered why water runs off a duck's back so easily? Aquatic birds have a very compact oily plumage, and if we watch a bird preening its feathers we notice that it frequently touches the base of its tail. This is because an oil gland there secretes a little oil that the bird uses to keep its plumage sleek. In the ducks, the oil gland is very well developed, and the body feathers are short and compact.

Everyone knows that many newly hatched birdlets are callow, naked, more or less covered with fluffy down. This is soon replaced with regular feathers growing in distinct tracts, surrounded even in adult life by naked patches.

The feathers are always shed or molted at least once a year. This regularly occurs toward autumn, and there is, in some cases, an additional molt in the spring. The males' winter plumage acquired after the autumn molt is frequently like that of the female. The male bobolink loses his handsome livery of buff and black and appears in a modest yellow-brown coat streaked with black, like that of the female. No longer is he the exuberant, rollicking fellow of midsummer. When he and the rest of the family move south for the winter, they are never called bobolinks, but are known as ricebirds or



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Fig. 4. A remarkably fine picture of an American egret on the wing. Observe the large wingspread and the compact streamlining of the body

reedbirds. There they grow fat and lazy, sun bathing, not on the beaches, but in the meadows and swamps where rice abounds. Doubtless this change of diet from insects in the north to starchy seeds in the south has an effect on their disposition, just as internal changes in their glands of internal secretion (endocrines) have much to do with producing the male's gayer plumage and ecstatic song in the brief summer season.

WING STRUCTURE

The examples of wings and tails shown in Fig. 5 illustrate some of the more noteworthy types of these structures. Birds with long narrow wings—such as the tern and also the albatross,



Fig. 5. Beaks. 1. Seed-crushing (Finch); 2. Flesh-tearing (Hawk); 3. Fishing (Tern); 4. Sifting (Duck); 5. Fishing (Grebe); 6. Probing (Curlew); 7. Tapping (Crossbill); 8. Catching insects (Nightjar); 9. Insect-eating (Warbler); 10. Probing (Plover); 11. Tubed Beak (Fulmar Petrel). Feet. 1. Perching (Finch); 2. Gripping (Eagle);

gull, swift, and swallow—are long-distance fliers, usually migrating over many lands. Those with short round wings—the sparrow and game birds—are short-distance fliers.

Birds with long narrow tails—for instance, the pheasants and sparrows—can rise suddenly into the air, but those with short tails—gulls, plovers, and eagles—must sweep along the ground for some distance before obtaining sufficient lift to rise. Those with forked tails—kites, swallows, and terns—can double and turn swiftly in the air. Birds use their tails as brakes and for steering, as well as for balance in flight. Some tails, as that of the lyre bird, are merely ornamental and are used in courtship. Other tails, such as that of the peacock, have coverts, or covering feathers, fitted over the tail.

A bird's wings do not merely flap up and down in flight, for this would only cause the bird to turn a back sommersault. The wings move with a screwlike forward-downward, backward-upward movement, for a moving bird tends to fall forward as well as downward, and flight must counteract this.

In the front of a bird's wing is a small bunch of feathers corresponding to the thumb, and easily seen when a pigeon banks round before settling. This is the bastard wing, corresponding to the slotted wing device on airplanes. By stretching it out the bird can increase the wing surface and thus slow down and glide before settling. Similarly, the ragged edges to the wings of crows and eagles—due

to the wide spaces at the wing tips—allow the air to circulate round the narrower edges of the quills and thus help to control wing surface. Birds that soar or hover, of course, must face the wind to maintain lift. The wings of the eagle have a pointed edge to give greater speed to its flight.

Some birds, such as the apteryx, ostrich, emu, cassowary, and penguins, have lost the powers of flight. The penguin uses its wings as flippers for swimming, and the ostrich uses its wings to increase its running-speed which is, perhaps, the fastest of all living things.

BEAKS AND FEET

The beaks and feet of birds, like their wings and tails, illustrate their habits. Birds with hook beaks—hawks, owls, gulls, and shrikes—tear flesh when feeding. Those with long narrow beaks—curlews, snipes, woodcock, and plover—probe mud. Those with broad shovel-shaped beaks, such as most ducks, use them to sift the mud for food. They have ridges, or lamellae, around the edge, making sieves.

The beaks of the tern and of the grebe are long and pointed and are useful for securing food by fishing. The crossbill has a peculiar beak, adapted to opening cones of conifers in order to extract the seeds. The fulmar petrel, a bird of great commercial value in the North Atlantic, has a most curious tubed beak.

Birds with very broad gapes—night hawks, swifts, and swallows—catch in-

3. Walking (Tern); 4. Webbed (Duck); 5. Lobed (Grebe); 6. Wading (Moorhen). Eggs. 1. Thrush; 2. Owl; 3. Nightjar; 4. Grebe; 5. Plover. Wings. 1. Short-distance (Sparrow); 2. Soaring (Eagle); 3. Long-distance (Tern). Tails. 1. Quick-ascent (Pheasant); 2. Slow-ascent (Gull); 3 and 4. Courtship (Lyre bird and Peacock)

sects in flight. Those with sticky hairs at the gape, such as the flycatchers, use them like fly paper to catch more food. Hard, conical beaks, as those of the finches, are used to crush seeds, but thin, soft beaks, such as those of the warblers, are used in feeding on caterpillars and soft insects.

The hummingbirds of the New World and the sunbirds of the Old World, have long slender beaks and long tongues to reach the nectar in the flowers on which they feed. Whereas the hummingbirds hover before the flower to feed, the sunbirds perch nearby.

Birds with very long toes, such as rails and jacanas, walk on floating lily leaves or very soft mud, and by distributing their weight, as if on snowshoes, avoid sinking. The ducks and other swimmers have webbed feet, or—as in the case of the grebes and phalaropes—they have lobes on each toe. Birds that dive deeply, like the loons, grebes, and auks, have their legs placed well to the rear. Perching birds have a well-developed hind toe, and can go to sleep on a perch without falling off because the tendons of the leg—joined above and below the joint and passing over it—are tightened and held taut when the bird sits back, thus “locking” the joint. The toes of the eagle are particularly adapted for carrying its prey by gripping it.

The long legs of the heron enable it to wade out into midstream to catch fish and other prey on which it lives. The crooked beak of the flamingo, which made such a useful croquet stick for Alice in Wonderland, is so arranged that the long-necked bird can hold its head down and swish its beak from side to side in the shallow water as it sifts for food. Birds of

prey, such as hawks and falcons, do not catch their food with their hooked beaks. They strike down their prey and carry it by means of their talons, and tear the flesh with their beaks.

On the seashore we can watch the sea gulls lifting crabs and mussels in their beaks and dropping them from a height on to the hard rocks to break their shells. Sometimes they drop them on the soft sands when they miss their aim.

AN ASTOUNDING GIZZARD

The stories about the ostrich's wonderful digestion are not due to the fact that the bird will eat anything and subsist upon nails, shoelaces, and all the other odds and ends that have been found in these birds. It is because birds have no teeth, and, to crush and break up their food, they have a hard gizzard, situated above the stomach. It is filled with grit or small stones that masticate the food as it passes through on its way to the stomach. The ostrich, being the largest of our birds, naturally requires larger grit than the others. When it cannot find enough pebbles it collects all sorts of curious objects and swallows them.

Birds of the air, as a rule, are in a great hurry. They have little or no time to chew their food, and have completely lost the teeth of their ancestors. Their beaks grab it; it is gulped down. Fortunately their stomachs are built to take care of it; a pouchlike crop stores and soaks it up; then the powerfully muscular gizzard, with its tough lining, and often little pebbles in its cavity, grinds it—thus the evils of hurried eating are avoided.

Compactness of build is seen in the omission of the right ovary and of

the right oviduct, which carries the bulky eggs before laying. A pair of big oviducts would seem to be out of the question, compactness, like intensive metabolism, being more or less a precondition for flight.

BIRD SONGS

From the primitive calls of birds have evolved their wonderful songs. In early spring there is often a war cry by the cock bird, when he has selected a nesting site. With "squatter's rights," or a strong sense of territorial possession, he announces his offer to any passing female bird and warns any rival male that "trespassers will be prosecuted." A bird will sing day after day from approximately the same perch, and in all probability, if a search be made, its nest will be found close by. Female birds, and those birds that live in colonies, rarely sing.

As the nesting-season duties make further demands on the male's time, however, the courtship song ceases. Again, at the end of the nesting season, in July or August, when birds molt their nesting plumes, there is a marked silence in the countryside. In autumn, however, some thrushes, robins, and song sparrows commence song again but in a less vehement manner, for now they are singing from individual happiness. Normally, a bird's throat pulsates in song, because its voice box, or syrinx, is very low in the windpipe, where its branches off to the lungs. With the mammals, of course, the voice box is almost at the top of the windpipe.

One of the most brilliant performances of bird song is the dawn chorus in spring, an expression of exhilaration welcoming the returning light. The reflection of the rising sun com-



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Fig. 6. The song of the western meadowlark, clear and sweet, is among the most beautiful music of any of our song-birds

ing into the sky before sunrise, is heralded by the earliest risers—such as robins, thrushes, and wrens. Before sunrise the peak of the volume of music is passed, and the chorus begins to ebb.

In the evening there is a chorus of quieter music at the end of day, and it is curious that the earliest risers in the morning—robins and thrushes—are the last to sing at night.

On the seashore, the feeding and roosting of the gulls and waders is controlled by the movements of the tide that covers and uncovers their food, and not by the coming of light and dark. Here is a medley of cries that vary from the "scree-arrrs" of the fishing tern to the bickerings of waders and the screams of gulls. These are heard even in the middle of the night if the tide is on the ebb.

NESTS—A STUDY IN VARIETY

The courtship of many birds includes the making of a mock nest, as in wrens and ringed plovers. Some birds present some of the building material to the mate—rooks and herons present pieces of stick; warblers proffer leaves; great-crested grebes, water-weed. The phalaropes are a strange exception in that the female courts the male bird, and after laying her eggs, leaves him to the nesting duties, much as the Australian emu leaves her eggs for her mate to hatch and rear. These are exceptions however, as in most cases both birds help to build the nest and incubate the eggs, with the mother bird doing

the bulk of the work. With some, such as the wild duck, the male has little to do with his wife after nesting starts, while many male birds simply bring food to the female and leave her to feed the young.

The hornbill of Africa and India nests in a hole in a tree, but as soon as the hen bird begins to sit, the male plasters up the entrance. She is kept a prisoner, in some cases for two or three months, while he feeds her through a small slit in the mud. In this way he makes certain that she does her duty!

The starling usurps the nests of other birds instead of making its own, and, as everyone knows, the cowbird and the European cuckoo lay their



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Fig. 7. "The gathering of the clan" might be the title of this picture, the "clan" being these hundreds of royal terns. Their gathering place is Cape Romain, North Carolina

eggs in the nests of other, more industrious, birds. The cuckoos of America, India, and elsewhere, make their own nests and hatch out their own eggs.

Birds do not lay their eggs all at once, but usually an egg a day—or, as with the birds of prey, an egg every other day—until the clutch is completed. The owls and some others commence to incubate as soon as the first egg is laid, and thus we may find youngsters of all ages and sizes in the nest. Most birds, however, do not incubate until the clutch is complete.

Some birds, like the auks of the sea cliffs, have but one egg in the clutch. Pigeons have two; plovers three; gulls four; most finches, thrushes, and blue jays, four or five; bank swallows six; the chickadee, flicker, and kingfisher, six to eight. Wild duck and ruffed grouse may have a dozen. The ostrich often has more than a dozen eggs in its nest; the quail from 12 to 16.

The most primitive nests are mere scrapes on the ground to hold the eggs, as with plovers and whippoorwills. The nests of larks, such as the European skylark are a little more developed, being hollows in the ground lined with a bed of grass. From this type we proceed to the more primitive adaptation of the nest to the tree, where it is free from the unwelcome attention of ground vermin. Such nests vary from the frail platforms of sticks of the jays and crows to the more substantial deep cup nests—held together with mud and fiber—of the American robin and other thrushes and the intricate weavings of various stringlike fibers that are the nests of the Baltimore oriole.

Some birds line their nests with feathers making a soft warm bed for the young. The eider duck plucks

downy feathers from its breast for this purpose. This is the eiderdown of commerce.

In Africa the weaver finches construct great communal nests in the trees. In Malaya the edible palm swift



L. W. Brownell

Fig. 8. The young cowbird has not only usurped the nest of this yellow warbler, but demands that the warbler feed it

makes a glassy nest of hardened saliva from its mouth, and this nest the Chinese use in making costly soups. Woodpeckers chisel their way into rotten wood to make a nest hole. Parrots excavate holes in tree trunks. The house wrens will nest in any convenient hole which they line with loosely placed, dry twigs. Swans and grebes make great floating nests in the reed beds of lakes, anchored to the reeds (Fig. 9).

WHAT IS EGG-SHAPED

We have seen that the colors of birds' plumage serve to hide or camouflage their bodies from predatory foes, or—in the gaudy plumages—to attract the female. The colors of birds' eggs, in some cases, may be protective.

Although we refer to "egg-shaped," as in the egg of the hen, there is really no general egg shape in bird life. The so-called egg shape, or ovoid, as represented by the egg of the thrush, is typical of the game birds and ducks, for the domestic fowl is a variety of the jungle fowl, one of the game birds. The shape of an egg often denotes the kind of bird that laid it as much as does its color. The eggs of snipe and plovers, for instance, are easily recognized by being pear-shaped (Fig. 26). Those of the grebes

and swallows are bi-conical, having each end pointed. Those of the night-hawk and whippoorwill are oval with each end rounded. Those of the owls and kingfishers are noticeably round or spherical.

The size of an egg does not correspond closely with the size of the bird. The egg of the guillemot of the cliffs is very large in comparison with the size of the bird.

Nor are all eggshells alike, although most birds lay smooth eggs. Some eggs, such as those of the woodpeckers, are very glossy. The eggs of the ducks are greasy, for they have to withstand the wet bodies of birds coming from the water; those of the grebes and cormorants have a chalky deposit. The eggs of the crested flycatcher are recognized by their markings of wavy lines as though someone had tried to write on them.

BIRD MIGRATION

The instinct of birds which leads to periodic mass migrations is one of the most interesting and mysterious of natural phenomena. It seems clear enough that the search for food is at the bottom of it. The mystery is in why and how the long distance flights over land and sea to definite destinations and the return journeys to the same breeding grounds, even to the same back yard, thousands of miles from their winter home, are accomplished.



Fig. 9. The nest and eggs of the little grebe, built among some lakeside reeds and floating on the water

As winter approaches in the north, the food supply wanes. Insects, which form a large share of the food of migratory birds, become scarce and less active. Movements into warmer, "buggier" localities would be expected. Treks southward to better feeding grounds a considerable distance from their breeding station are not unusual and is known to be the common occurrence for many North American species. In years past, evening grosbeaks were unknown in New Hampshire; they wintered in the northwestern states, breeding in western Canada. Then they began coming eastward as winter visitors. Now their regular return has apparently become a habit. The question arises as to how such acquired habits in the remote past have been replaced by deep-seated, inherited tendencies to take to the air in large flocks at night, when such birds usually rest, and move southward thousands of miles. And what drives them back northward in the spring to their old breeding grounds? It can hardly be lack of food, for the tropics are not likely to be short of insects, seeds, and whatever a bird likes. Is not the northward journey perhaps an inner urge toward reproduction, like that which drives salmon at the approach of the breeding season to swim, in almost frantic haste, from the sea, hundreds of miles upstream in their native river to the shallow pools where they were born?

Physiologists tell us that a partial explanation to that urge is chemical, i.e., seasonal changes in the internal secretions which circulate through the blood and spur on reproduction; but how has it come about that this restlessness caused by changes in the composition of the blood continues until the salmon have reached the

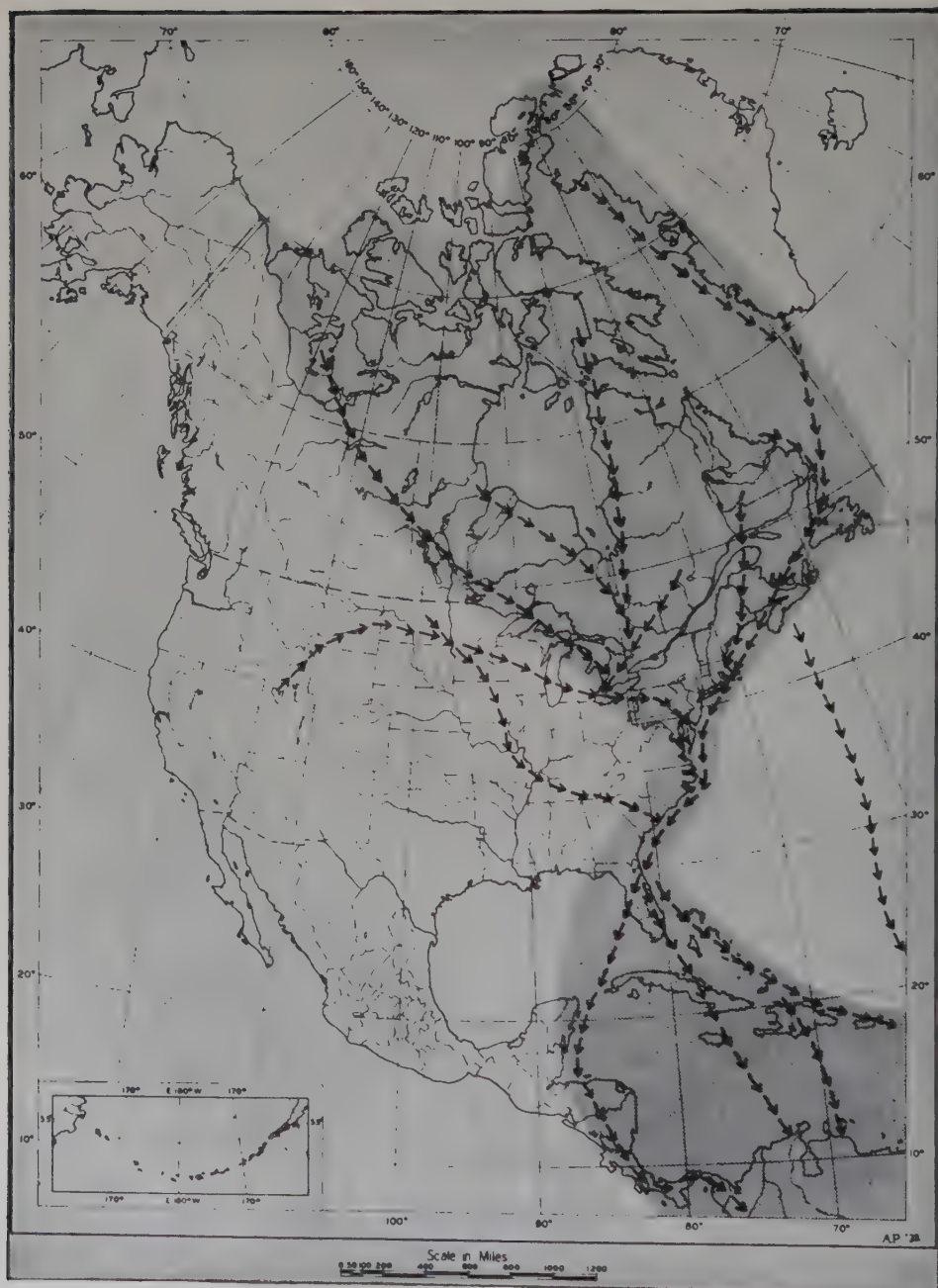
headwaters of the river, or the birds have arrived at their distant nesting grounds? Has it taken millions of years and the elimination of millions of vagrant, misdirected salmon and birds until natural selection of the fittest has produced these wonderful results?

LANES OF TRAVEL

Birds migrate, by and large, within broad lanes of travel, extending chiefly north and south. To a certain extent these lanes follow shore lines and river valleys or alongside mountain ranges, but the sight of such landmarks does not tell the whole story, for some birds migrate over wide stretches of water where there are no landmarks and even through dense fogs. Our ruby-throated hummingbird, speeding across the Gulf of Mexico, more than 500 miles in one all-night flight, must fly "blind"; it would seem to have some sort of inner compass.

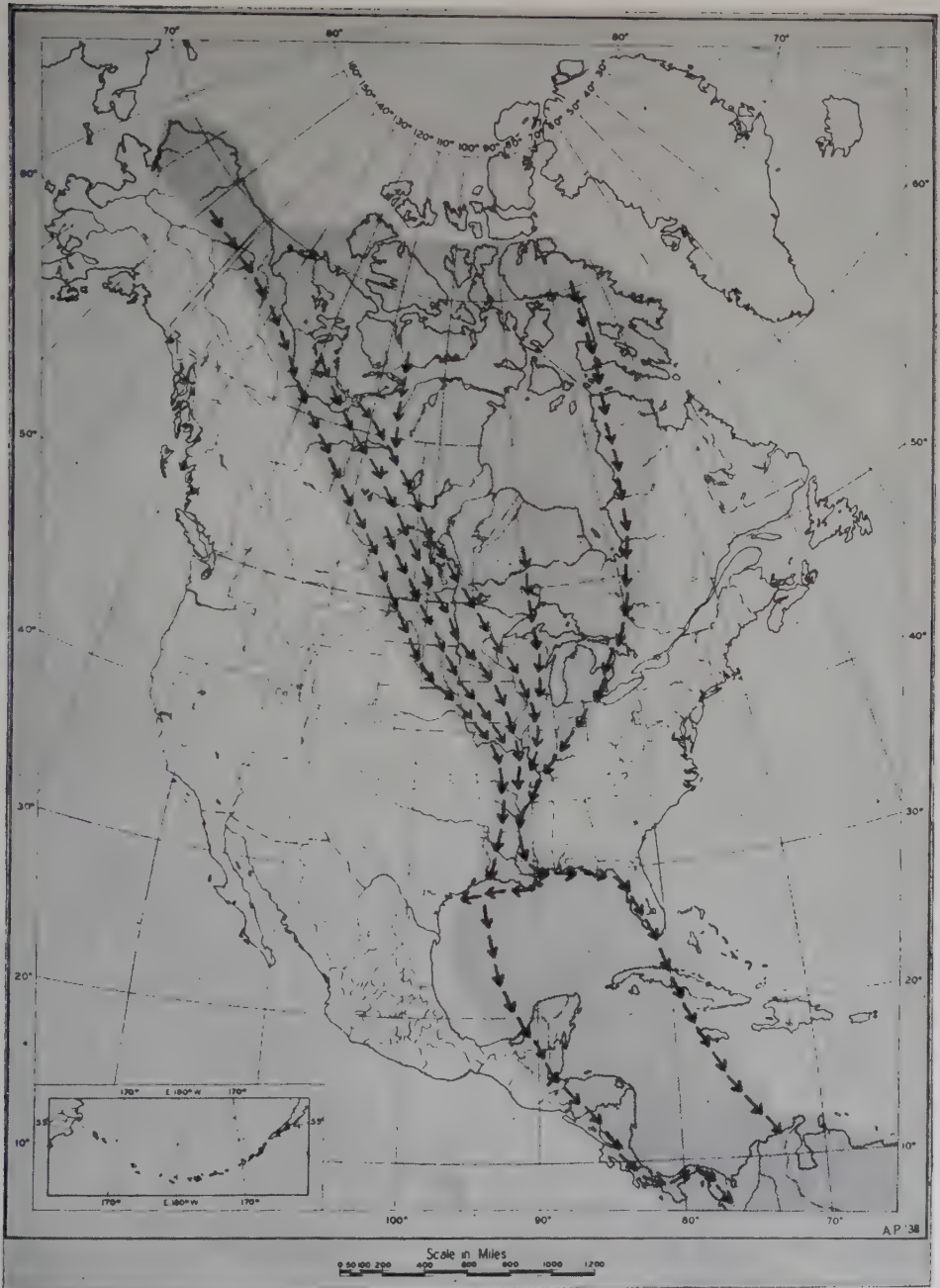
No one knows for certain what this inner compass which provides such a superhuman sense of direction may be. Perhaps the internal ear, i.e., the semicircular canals, which keep it balanced in a level plane and help it to go straight (the right ear checked by the left), may explain why it goes on and on unswervingly all night. Our own sense of direction is so poor, as compared with that of birds, or even of cats, horses, and some of the other mammals, that we hesitate to claim that such a marvelous sense of direction exists.

The homing instinct of the carrier pigeon is worth study in this connection. One interesting aspect is that the instinct does not become established until a bird has nested for the first time. Thereafter, it feels the pull back



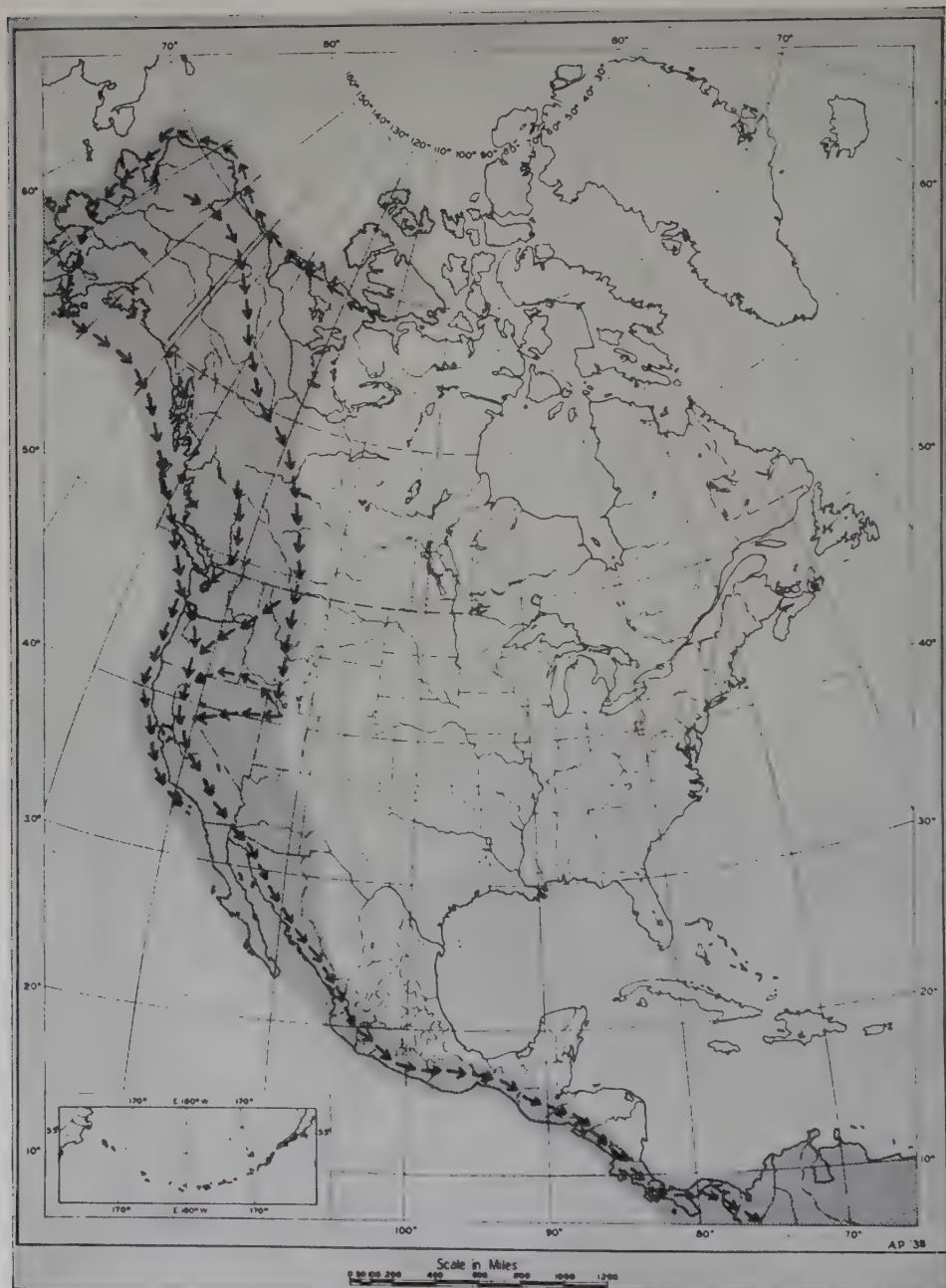
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Fig. 10. The Atlantic flyway extends from the offshore waters of the Atlantic coast west to the Allegheny Mountains, where it curves westward through northern West Virginia and northeastern Ohio, and continues to the Arctic coast of Alaska



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Fig. 11. The Mississippi flyway contains the longest migration route of any in this hemisphere. Conditions are ideal, and from the mouth of the Mackenzie to the delta of the Mississippi—more than 3000 miles—there are no mountains, or even hills



U.S. Fish and Wildlife Service

Fig. 12. The Pacific flyway includes units of the Arctic Archipelago and much of the Rocky Mountains, as well as the Pacific coast region of Canada, the United States, and Mexico. Arctic terns, gulls, and ducks make long migrations in this flyway

to its own home. The same is found to be true of young birds returning to the north. They may have no memory of the nest they left as fledglings, but do recall the general vicinity. It is usually an older robin which returns to build over the same doorstep, or an older wren which builds its rude nest of twigs in the same box. This and many other facts about migration have been proved by "bird-banding," fixing aluminum bands to the legs of wild birds, either as nestlings or adults caught in large, comfortable traps and set free. Later, the trapper takes count of those which have returned.

Young birds often flock together and go south by themselves; those flocks usually follow their elders. Males of certain species, such as wrens, orioles, and red-winged black-birds, often travel ahead of the females and stake their claim over a definite area where they are to establish their households, and, to defend these homes against all comers, loudly proclaim their rights by songs.

The instinct to move on is not only seasonal, it is also social, for, when the trip is interrupted, stragglers often fail to go on, even though faced with possible starvation or death by cold.

The distances covered by different birds varies enormously. Some, such as bobwhite, cardinal grosbeak, chickadee and woodpeckers are hardly migratory at all; others, of which the golden plover is a classical example breed on the arctic islands and barrel tundras north of Hudson Bay, travel southward 8,000 miles to cross the equator to the pampas of Argentina. The trip from Nova Scotia to Argentina appears to be a non-stop flight of 2,400 miles in 48 hours.

In migrations, birds travel in leisurely fashion, more often by night than by day, when they stop to rest and feed. Speed of birds' flight is never rapid compared with that of airplanes. Swallows as a rule fly only 25 to 30 miles an hour; hummingbirds from 45 to 55 miles; swifts and duck hawks are thought to exceed 100 miles an hour.

Storms frequently hold back the migrants, especially small birds, and highly illuminated light houses are fatal to many. Like moths fluttering around an electric light, birds are fascinated by the beams, and, especially in a fog, become dazzled, and either dash against the glass or flutter about it until they fall exhausted. Neither red nor flashing lights are as destructive as steady, white ones.

Although every species has its own north-south lane of flight, within which it may be expected to travel, it is possible to map out three principal "flyway systems" in North America which very roughly correspond to the east-west time areas: Atlantic, Mississippi, Central, and Pacific (Figs. 10-12).

BIRD ORDERS

Birds are grouped, or classified, by their external and internal form or structure, into twenty-seven or more "orders." As a whole, they are one very distinct class, viz. *Aves*. In other words, we have no difficulty in distinguishing any modern bird from a reptile, on the one hand, or from a mammal, on the other. So we speak of the class Reptilia and the class Mammalia as coordinate with *Aves*. No one would be likely to confuse the duck-billed platypus with a bird, in spite of its ducklike bill, webbed feet, and the fact that it lays a real egg.

The following bird classification is that of Dr. Alexander Wetmore of the U. S. National Museum.

ORDERS

1. Ancient orders including birds with teeth (*Archaeopteryx*, *Hesperornis*, *Ichthyornis*)
 2. Ostriches
 3. Rheas
 4. Cassowaries and emus
 5. Moas (extinct)
 6. Apteryx
 7. Penguins
 8. Divers (Grebes and Loons)
 9. Petrels, Fulmars, Albatrosses
 10. Pelicans (Gannets, Cormorants, Snakebirds)
 11. Herons, Flamingoes
 12. Ducks, Geese, Swans
 13. Hawklike birds (Falcons, Hawks, and Old World Vultures, American Vulture or Buzzard)
 14. Fowllike (Grouse, Quail, Peacock, Turkey)
 15. Hoatzins ("finger climbers")
 16. Cranes (Rails, Coots, Bustards)
 17. Plover-form (Jacanas, Plovers, Snipe and Woodcock, Gulls, Auks)
 18. Dove-form (including Dodo)
 19. Cuckoos
 20. Parrot-form
 21. Owls
 22. Goatsuckers
 23. Swifts and Hummingbirds
 24. Trogons
 25. Kingfishers and Hornbills
 26. Woodpeckers (Toucans, Honey Guides)
 27. Sparrow-form
 - (a) Tyrant Flycatchers
 - (b) Lyrebirds
 - (c) Songbirds ("Oscines")
- Songbirds
Families:
1. Larks
2. Swallows
 3. Crows and Jays
 4. Birds of Paradise
 5. Bowerbirds
 6. Titmice
 7. Nuthatches
 8. Creepers
 9. Wrens
 10. Mimics (Mockingbirds and Thrashers)
 11. Thrushes
 12. Old World Warblers
 13. Kinglets
 14. Waxwings
 15. Shrikes
 16. Starlings
 17. Sunbirds
 18. Vireos
 19. Wood Warblers
 20. Weaver birds
 21. *Icteridae* (Bobolink, Meadow Lark, "Oriole," Cowbird, Red-winged Blackbird)
 22. Tanagers
 23. Finches
1. The strangest of birds were those which had teeth, a long, feathered tail, and resembled the reptiles of their time, some of which were buried with them in silt or sand which hardened into rocks. Our old friend, the *archaeopteryx*, the reptilian bird of Bavaria, had the longest tail of all, and seems to have been an excellent flyer. Another good flyer was the fish bird of Kansas (*Ichthyornis*). It was about the size of a pigeon with plenty of recurved teeth wonderfully adapted for catching and holding slippery fish. Its keeled breastbone gives a clue to the large size of its wing muscles. Another ancient Kansas bird with teeth, *Hesperornis* (meaning western bird), was a splendid swimmer but could not fly, which may have contributed to his extinction.

Much more recent than these specimens found in the Kansas chalk deposits and, in fact, extinct only for a few hundred years—just a moment in the vast span of geologic time—are the bones of moas found in New Zealand. They had the general set-up of the dinosaurs of western Massachusetts, stalking about on powerful legs, with no trace of any wings. Some were over nine feet high, and their eggs were about twice as large as those of the ostrich.

Much like the moas, with even more powerful legs, were the elephant birds, or rocs of Madagascar. They were nine or ten feet tall, some of the dozen or more species a little smaller. Their eggs, many shells of which have been found buried in the sand near the shore, are enormous, more than 13 inches long and 9 inches wide, holding over two gallons. These shells, as one would suspect, are so thick and strong that natives of Madagascar have used them as water jugs.

2. Ostriches are giants among modern birds, standing eight feet high and weighing 300 pounds. Those of North Africa are called "camel birds" from their long neck; the neck and thighs are pink; in the South African variety these parts are bluish. The latter is the kind raised extensively for their plumes in our southern states, especially California, Arizona, and Florida. The male is black with white plumes; the female's feathers are gray-brown, so she is well hidden when she lies upon sandy ground. Though not birds of the air, they spread their wings when they run, to gain speed. They can easily outstrip a galloping horse and make 25 miles an hour, with a stride of 25 feet.

The cock is polygamous and escorts a harem of three or four hens which



N.Y. Zoological Society

Fig. 13. This North African ostrich looks as if he had been surprised by a candid-camera photographer. When the ostrich is pursued he does not bury this portion of his anatomy in the ground, but runs swiftly away, so swiftly that he usually escapes

lay in the same nest, a shallow excavation in the sand. He sits on the eggs at night and guards them by day. Since the sun often furnishes all the necessary heat, he often kicks a little sand over the eggs, of which there may be as many as 30, and joins his wives in their search for food. This consists of anything animal, vegetable, or mineral which comes their way and can be conveniently swallowed.

When the chicks are hatched and follow their parents about, the male, being a good father, sometimes tries to decoy away an intruder; he circles around his flock, wings outspread, falls helpless, and appears to be badly wounded. The ostrich, as it were, "plays possum."

The fable of the hard-pressed, stupid ostrich burying his head in the

sand to escape his enemies dates back to the most ancient authorities. It applies so aptly to human self-deception that it has become a convenient descriptive figure of speech. Possibly the behavior of some father ostrich doing his best to draw attention from his family may have started the rumor. Those who have hunted the ostrich will attest otherwise.

3. The rheas of South America are only about two-thirds the size of African ostriches. They are found on the plains of Argentina and neighboring countries, have three toes instead of two, are tailless, and their wing plumes, commercially used for brooms, are greatly inferior to those of the African ostrich.



American Museum of Natural History

Fig. 14. The kiwi is a native of New Zealand, wingless and with nostrils at the end of the long beak. It lays only one or two eggs at a time, but these are unusually large for a bird its size

4. The emu hails from Australia, cassowaries from New Guinea and other Malayan islands. Both are covered with long hairlike feathers, but the cassowary's head is rather bare and on the top of it is a bony helmet

or casque. Emus prefer sandy plains; cassowaries are forest birds and avoid the sun. Both are strictly monogamous. The males are not only content with one wife, but they do most of the incubation, lasting seven or eight weeks, and take care of the young. The eggs of both are dark green, with a rough, granulated surface.

5. The moa was a resident of New Zealand. It is supposed to have been exterminated by the natives, who ate its flesh, about 500 years ago.

6. The apteryx, or kiwi, of New Zealand mountains, though not yet extinct, has all the earmarks, so to speak, of an ancient bird. In build it is much like the moas of its native land, though smaller. In size it is like an ordinary hen, covered with small feathers. The Maoris regard it as a good table bird. Having only stumps of wings beneath its feathers, it is said to be wingless, hence its name "apteryx" (Greek for "no wing").

It spends the day in a hole or cave, striding about at night with a quick, nervous gait in search of food. Its eyes are small and sight is probably not very acute; at any rate, it is dazzled by direct sunlight. Its sense of smell is extraordinary; its nostrils, unlike other birds, except the moas, are at the tip of its very long, curved beak, and the nasal passages running back into its head are very large, so it finds its food in the dark by smelling and by feeling with its beak.

It lays one or two eggs only, at the end of a hole in a bank, lined with grass or leaves. These eggs are enormous for a bird so small, weighing about a pound, equal to about one-fourth of the kiwi's own weight.

Its cry is a loud whistle suggesting its name "ki-wi"; the young have a high-pitched and kittenlike chuckle.

When an apteryx is disturbed, it growls and rolls itself up in a ball. Having been up all night, he is likely to be sleepy in the daytime and frequently yawns.

7. Penguins have a superficial resemblance to some of the auks, especially the extinct great auk which could not fly. Most auks, however, can fly and are really more like gulls, while the penguins are more like loons. Moreover, penguins are found only in the southern hemisphere, especially in cold, antarctic waters. One species only is tropical, *Spheniscus mendiculus*, "little beggar," which is found in the Galapagos Islands.

Penguins are curious, sociable bipeds which trot about rapidly on land on their strong, stumpy legs and webbed feet. They swim by using their wings as paddles, which make an alternating rotary motion, while their feet serve as rudders. On shore they stand erect in a dignified, human manner, and gather in huge solemn assemblies at the breeding season. They build rude nests in holes or in crevices in rocks, and lay two white, chalky eggs. Although pugnacious, they are good parents, sit patiently during the six weeks' incubation, and feed the blind young for a long period. Some species bark like dogs; the "Jackass," or Cape penguin, of South America and South Africa brays like a donkey. Those of the small Galapagos species, exhibited at the Bermuda Aquarium, amuse themselves (and spectators) by lining up on the diving board, plunging, and circling round to take another, and another, plunge and swim.

8. A good example of the divers is the loon, or great northern diver. Its laughing cry may be heard in the summer at many lakes in northern

New England. By no means crazy, as its strange, loud laughter may suggest, it is a solitary, shy fisherman, quick as a flash in diving at the least sign of danger, swimming far away under water to a safer place, then



N.Y. Zoological Society

Fig. 15. The penguin is usually shown waddling on land. His natural habitat, however, is in the water, where he uses his rudimentary wings as flippers

bringing only its head to the surface. In its rough nest on the ground, two dark greenish-brown eggs are laid. It breeds as far north as Greenland and Labrador and southward to northern New York and New England.

The loon is a large bird about the size of a goose; it stretches out to a full three feet; grebes are smaller. The pied-billed grebe and the horned grebe are about a foot long; Hoellbell's grebe twice that size. The grebes have flat, lobed toes, not webbed like those of the loons. Grebes lay six or eight white eggs in nests, made of brokendown reeds and aquatic plants, placed among the rushes



Fig. 16. A great crested grebe sitting beside her nest. A curiosity of the great crested grebe is that the sexes are almost identical in appearance. Notice the long sharp beak and the short legs with lobed toes

by the lakeside and almost floating on the water.

9. The petrels and albatrosses glide above the deep sea and are swimmers rather than divers. They have peculiar tube-nosed beaks. The nostrils open into separate tubes running like a double-barrel gun along the top of the bill, the sheath of which seems to be made of several pieces.

Albatrosses are large birds, some of them three feet long, with an enormous wing-spread of 10 or 12 feet. They follow a ship with tireless soaring flight all day long, circling about for refuse or picking up fish and other denizens of the sea brought to the surface in the wake of the vessel. More species are found south of the equator than north of it, but several are common in the North Pacific. They nest on islands, heaping up a mass of leaves, grass, and sea moss, all held together by mud; in a depression on the top, they lay their eggs. Their voices are scarcely melodious, and are variously described as like a bray, croak, cackle, whine, or diabolical scream.

Petrels are small, dark-colored birds. The stormy petrel, or Mother Carey's chicken, is the size of a robin. It ranges over the surface of the sea from its breeding grounds in Scotland, Ireland, and West England, where toward the end of June, in a hole or crevice, it lays a single white egg. But it spends the summer mostly on the wing, sleeping on the waves at night. From its habit of using its webbed feet in tripping along over the surface of the water in its soaring flight, came its name petrel, or "Little Peter," from St. Peter, who tried to walk upon the water.

Wilson's petrel breeds only on islands in the oceans south of the equa-

tor, and migrates northward at the end of the breeding season. In April they are found flying north along the coast of Argentina, Brazil, and North Carolina, and during the summer follow the Gulf Stream as far north as Newfoundland. Some are seen off the coast of Portugal.

10. The pelican tribe includes first of all the gannets and boobies. The common gannet, which means "little gander" and is sometimes called solan goose, is really unlike a goose, except for its size, its long body, and webbed feet. It is three feet long, with a wing-spread of over four feet, the largest bird of our Northern Atlantic seacoast and the most powerful. It ranges across the whole North Atlantic and breeds on both sides of it; here, on Bird Rock and Bonaventure Island in the Gulf of St. Lawrence; on the other side, on Bass Rock at the entrance of the Firth of Forth in Scotland. It is white with feet and edge of wings black.

The brown pelican of the Southern Atlantic coast from South Carolina to Texas is a huge, powerful bird with a pouch hanging from its bill, into which it can gather and carry home an excellent basket of fish. It has a wingspread of six and one-half feet and is four and one-half feet long. H. K. Job says of them: "The sight of the advancing wedge or line of great Pelicans, with their heavy flappings and intervals of soaring, is impressive, as is the amazing headlong plunge into the sea after fish." Sometimes "The smaller laughing Gull follows the great Pelican and hovers above the spot where he plunges. The Pelican soon emerges, holding the fish which it has seized in its bill. The fish, perchance, must be turned, and a mouthful of sea water ejected.



Fig. 17. The gannet sitting on its nest. The gannet is a sea bird, lives on fish, and has no nostrils. Its habitat is the North Atlantic where it breeds in large colonies on rocks and cliffs

While the Pelican is arranging matters, the Gull alights on the great beak, leaning over to watch. No sooner is the bill opened than the sly gull reaches in, seizes the fish, and flies away, we may well imagine, laughing. The solemn old Pelican sits there blinking, too much astonished at first to move. Finally the dread truth seems to dawn on the dull mind. With a few disgusted flaps, away it goes in pursuit of another fish."

Gannets usually fly in small flocks, 60 to 100 feet above the water, watching for prey. When a school of fish appears, down goes the gannet like a flash, its wings nearly closed. A few seconds later he emerges, swallows his catch, and up he goes for another survey.

Nests are built on ledges rising from the sea; only one egg, covered with a chalky deposit, is laid, but the cliffs are often covered with thousands of nests.

The booby is the somewhat smaller gannet (30 inches long) in the West

Indies and in the Pacific off Panama and the South American coast. It is brown with a white belly. He nests in flocks in low bushes—a rough nest of sticks and weeds—laying two eggs. Each pair of boobies claims with its nest an area six or eight feet in diameter, which they defend with furious vigor, uttering hoarse screeches. Probably this totalitarian disposition and method of speaking have awarded them their unflattering name.

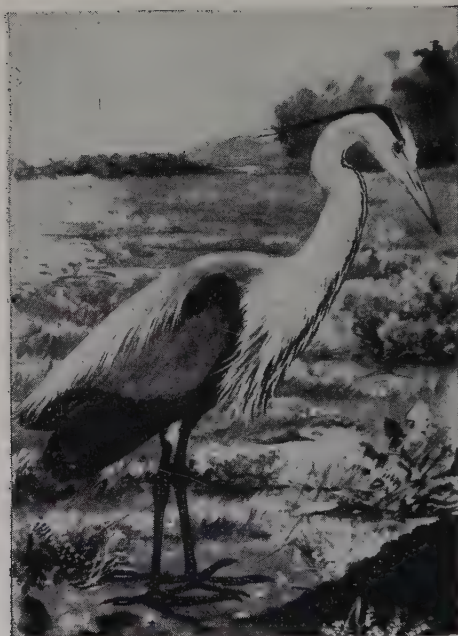
Cormorants may be recognized by remembering their common name, crow duck. They are great divers and below-surface swimmers, pouncing down from a low perch, not from the sky, and using wings as well as webbed feet in swimming. Their slender, curved beak is hooked at the tip, an effective fishhook. When properly trained by the Japanese they learn to assist in fishing operations. They are northern birds in America and mostly follow the sea.

Snakebirds, or darters, have a long, slender, snakelike neck and long, sharp, and slender beak, so that the front part of them looks like a heron. But the feet are webbed, the tail long and fan-shaped, quite unstorklike. They are able when swimming on the surface to sink backward out of sight or with only the snakelike neck protruding. They are fresh-water, semi-tropical and tropical birds, of the lower Mississippi, Texas, and Florida.

11. The heron order includes long-legged waders, with long, slender toes



Fig. 18. The cormorant, a larger relative of the gannet, is used for fishing in Japan



U.S. Fish and Wildlife Service

Fig. 19. The long flexible neck and the long tapering beak of the great blue heron make him an excellent fisherman

without webs. They have slender necks, and their bills are adapted to their various food-habits. Spoonbills are useful in catching frogs, insects, snails, and small fish; probably the curve downward of the long, slender bill of the ibis has its advantages in dispatching crayfishes and insects; our herons have exceedingly sharp, straight beaks; but the shoebill, or whalehead, of the Nile has a broad, heavy shoe-shaped organ hooked at the end. This curious heron feeds on the bichir, an 18-inch fish of the Upper Nile, which has an enamel coat of mail over it that needs to be crushed before swallowing.

Our great blue heron is the largest and most stately of American herons, four feet in length, with legs so long that he wades deeply into the pond

or lakeside. There he stands rigid as a statue till a fish, frog, salamander, or what not, appears and is seized by a flashing stroke.

Except during the breeding season, he is a solitary bird, fishing up and down the river or lake, cautious but not too much so for his own good. Sometimes he makes havoc of fingerling trout at the hatcheries and annoys the fish culturist, but generally he does mankind more good than harm, for now and then he leaves the water and feeds on field mice and other destructive rodents. Certainly a bird so majestic and dignified, so handsome and so strange, deserves to be let alone by gunners.

During the breeding season great colonies gather on islands or isolated swamps, where they build huge nests of twigs and grass in which three to six greenish-blue eggs are laid.

The green heron, a smaller bird (length 18 inches) is always solitary. Occasionally a few pairs may happen to be associated, but this happens infrequently.

The bittern is an intermediate-sized heron, a brown and yellow bird streaked with black and white with a comparatively short, thick neck. Its streaked coloration, as it stands up straight among the reeds, makes it almost invisible. Its ventriloquism is engaging; first it makes with great effort the sucking sounds of an ancient wooden pump in sets of three syllables, "plunk-a-lunk," so that it is called sometimes "thunder pumper." Heard at a distance, the three notes blend into one sound like driving a stake, hence another local name, "stake driver."

The note of another common heron is a loud, raucous "quawk" as it flies overhead in the evening toward its

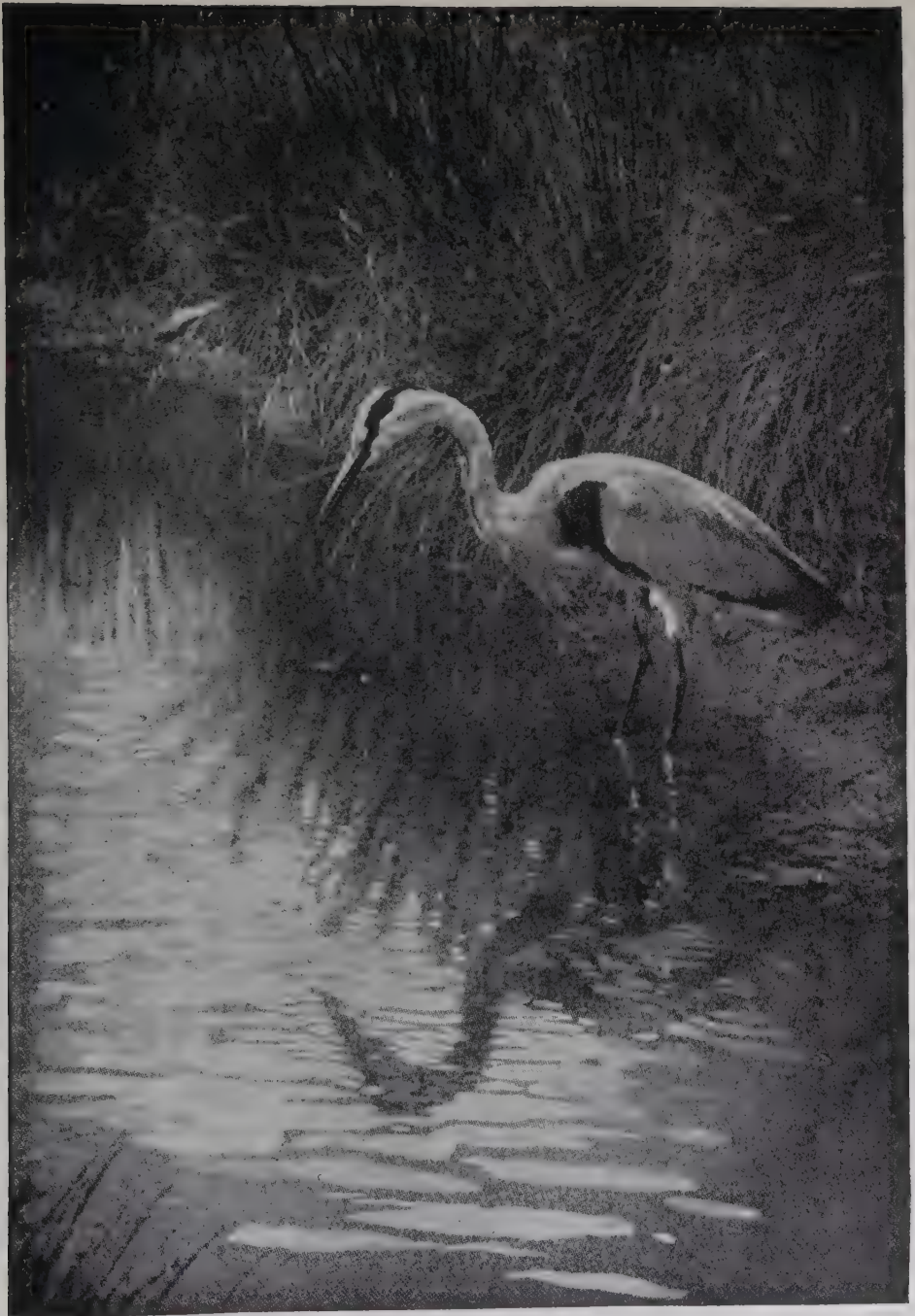


Fig. 20. A heron fishing. This species (*Ardea cinerea*) is widespread through Europe, Africa, Asia to Australia

feeding places in shallow ponds. This is the black-crowned night heron, or "qua-bird," from its call note. It is gray, white below, and with a black crest. It nests in great colonies in trees or on the ground, laying three to six pale sea-green eggs.

12. The ducks and geese and swans are so numerous in species and so generally well-known in form and habits that we can only skim the surface of this order. Their webbed feet, with legs far back, make them excellent swimmers and divers but waddling walkers. The swan's neck permits it to explore the bottom of a shallow pond for its vegetable food without having to dive for it.

Wild ducks are of two main groups: the smaller species are the river ducks, which frequent such shallow waters that diving is unnecessary. They seldom live in great flocks. Sea ducks, on the other hand, are of large size. They have the hind toe broadly lobed or

webbed, which helps in diving, and they dive deeply for shellfish (clams and snails) and choice bits of seaweed. They feed by day, and at night often go out to sea in large flocks.

Of river ducks we can mention only two, the mallard and the beautiful wood duck. The mallard is a most common wild duck of game preserves throughout the northern hemisphere, a hardy bird, easily domesticated. The male, in winter has a green head, gray-brown back, white collar, purplish-chestnut breast, and gray belly. In summer, he looks more like the female. She, as in ducks generally, is less handsome; variegated yellowish brown. Mallards are exceedingly noisy. Their insane laughter can hardly be called a quack, which has come to be our interpretation of duck language. The female nests on the ground, using grass or leaves lined with down; there are six to ten olive-colored or yellowish green eggs in a



U.S. Fish and Wildlife Service

Fig. 21. A pair of wood ducks in the foreground and mallard ducks in the background on Sweet Water Lake, in a national game preserve in North Dakota

clutch. She is a watchful mother and teaches her ducklings to be good at hiding among the water plants.

The wood duck is less common but the most resplendent. Males are green, blue, and purple above; red, yellow, and white below. The females are protectively colored, brown above, yellowish brown and whitish below. Both sexes have long crests extending backward from their heads. The wood duck, as its name suggests, is a woodland bird, often wandering away from ponds and streams to look for nuts, acorns, and insects among the trees. Its nest is usually in a hollow tree, well up from the ground (20 to 40 feet). It is lined with feathers and in it are laid eight to fourteen cream-white eggs.

Everyone who spends spring or fall in the country is sure to hear the honking of the V-shaped flocks of Canadian geese as they pass overhead in their migration northward toward their breeding grounds in Canada or northwestern states, or southward in the fall toward Florida, Texas, or southern California. They are about the size of a domestic goose, three feet or slightly more in length, brownish gray, head and neck black with a broad collar of white. They dine chiefly on vegetation, grain in stubble fields when they can get it, or the roots of water plants. The nest of grass, reeds, and leaves, lined with down, is usually placed on a mound



Fig. 22. The head of the Pondicherry vulture. Notice that the front of the head is almost free of plumage. This is nature's way of ensuring that the bird is not fouled by the carrion it eats

in the marsh. In it are laid six or seven white eggs.

Wild swans are seldom seen during their migrations, they fly too high. The whistling swan is pure white, breeds in northwestern Canada and Alaska, and migrates as far as South Carolina, Louisiana, Texas, and California. The trumpeter, five feet in length, six inches larger than the whistler, also pure white, is a vanishing species of the fresh-water lakes of northern United States. During the nineteenth century, when they were abundant, they were ruthlessly destroyed by hunters.

13. The day-flying birds of prey have a strongly hooked beak with a soft waxlike membrane (cere) surrounding the nostrils at the base. They have three toes pointing forward, one backward, each terminating in a strong, sharp claw. Vultures differ



U.S. Fish and Wildlife Service

Fig. 23. The bald eagle has become the national symbol of our country. There is no scarcity of feathers on his head, but since they are white they give him a somewhat bald appearance

from eagles, hawks, falcons, and ospreys in having clumsy feet not adapted for seizing and holding prey. They feed on dead animals and are bald. Of these scavengers, there are in temperate America three species, turkey vulture (or buzzard), black vulture (carrion crow), and the now almost extinct California vulture (condor). They have a demoralized appearance and do not take the trouble to make nests, but lay one or two eggs in a hole or upon the ground. They are majestic flyers and are certainly useful to mankind, whether fully appreciated or not.

The eagles, the golden and the bald, or white headed, certainly need

no introduction to Americans. The latter is not at all bald. Its head is covered with white feathers, elsewhere it is dark brown; its shanks are bare for an inch or more above the toes, while the golden eagle's feet are feathered to the toes.

The golden eagle is now seldom found anywhere in this hemisphere except in the mountains of the western states. It is a little larger than our national emblem with the white head, which is 100 per cent American in its range. Both are superb flyers. The male is said to shout, in a high, clear strain, "cac-cac-cac"; the female has a harsh, disjointed cry like the laugh of a maniac. They mate for life; and year after year the same pair use the same bulky nest of sticks, roots, and grass in a high tree. Only two, or rarely three, rough, white eggs are laid.

The duck hawk, or peregrine falcon, may be selected to illustrate the numerous species of hawk. It is the American representative of the European falcon from which it differs only in its clear white, unmarked throat and breast. Its head is a dark slate color, back bluish ashen, belly and sides yellowish, barred with black or dark brown. It is only 18 or 19 inches long, but has a wingspread of over 40 inches. Its flapping flight is quite unlike the soaring of most hawks. Large birds such as pigeons, partridges, and ducks are attacked and killed by it, which explains why in ancient times it was trained for hunting in falconry.

14. The fowl-like birds are runners, spending their time mostly on the ground rather than in flight. They have a heavy body, a stout, short beak, and strong legs, with the front toes slightly webbed, the hind toe raised. Their wings are short, rounded and arched. They are more or less

polygamous. The female lays numerous large eggs and the young run actively around as soon as hatched.

The bobwhite is the commonest example of the quails, a small, trim bird only 10 inches long, of mixed colors—chestnut, black, ashy, and red-brown—in streaks along its sides and V-shaped black spots on its breast. The male has a white throat and line above its eye and a black band below it. His cheery note “bob-white?” is repeated everywhere he goes. Sometimes two females use the same nest, but that is rare. From 12 to 18 pure white eggs are laid in the simple nest of grass and leaves upon the ground. The chicks keep together with their mother, and sleep together in a cluster. The male helps find food for the family and is known to take full charge in case the mother dies. They migrate only short distances southward in the fall, and do not live in the extreme northern states, where snow and cold weather make life difficult for them.

The ruffed grouse, or partridge, of the northern states is larger than the bobwhite, 18 inches long, and known by its crest and the purplish black ruff on neck and shoulders, which it expands when mating or excited. Its back is reddish brown, spotted with yellowish white and gray. The broad, fan-shaped tail is of a brighter brown crossed with concentric black bands, with a broader one near the tip. It is a shy bird of the forest, and learns to be wary of the hunter, though in the winter when food in the woods is scarce and gunmen not too prevalent, it flies stealthily out around houses where the wild fruits of sumac, barberry, and other shrubs are to be gathered. When suddenly approached in the woods, it rises with a terrific

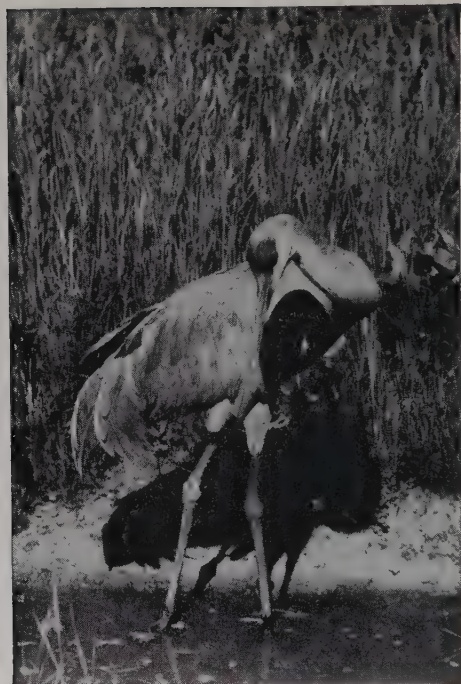
whir, made by the beating of its wings. Often in the deep woods one hears the “drumming” of the male, a rapid succession of low-pitched, thumping sounds, made by the wings striking the air and, probably, the inflated air sacs of the body. This is a call to the neighboring females, as well as a salute or warning to distant rival males, who often respond.

In its simple nest of leaves, grass, and roots in a slight hollow on the ground concealed in underbrush, the female lays 10 or 12 creamy brown eggs, usually unspotted. The chicklets scatter about doing their best to find their own food, but the watchful mother keeps her eye on them. If a marauder appears, she feigns a broken wing and whimpers in make-believe distress while the chicks hide under fallen leaves and “freeze” in their



L. W. Brownell

Fig. 24. The ruffed grouse, shown here on his nest, is a highly prized game bird



N.Y. Zoological Society

Fig. 25. The sandhill crane was formerly abundant throughout eastern and central North America, but is rapidly becoming something of a rarity

tracks till they get word that the coast is clear. Within three weeks they begin to fly and roost with their mother in shrubs and low trees.

Much like the ruffed grouse in size, color, and general appearance is the prairie chicken of western Mississippi Valley states, but, instead of ruffs upon its neck, it has a pair of prominent, sharp feather tufts. The male makes a loud, prolonged booming sound, which may be heard a mile or even two miles when, in early spring, flocks gather for mating. This is accompanied with violent antics: erection of the feather tufts on the neck, spreading of the tail, drooping of the wings. All this, of course, greatly in-

terests and probably excites the female and is a challenge to competing males.

15. We have already referred to the hoatzin, which has claws to help it climb trees. The adult bird has a strong, musky odor, from which it has taken the name stinkbird.

16. The cranes and their allies, the rails and coots, are inhabitants of the marshes and, in general, are runners, more like grouse and the domestic fowl than like herons and snipe, which some of them superficially resemble. Like the grouse tribe, their hind toe is raised slightly above the others so that generally it does not touch the ground. The sandhill crane, for example, is a big bluish gray, stork-shaped bird of Louisiana and Florida. It prefers dry land and vegetable food such as corn and other grain, roots, etc., but includes mice, snakes, frogs, and insects in its bill of fare.

Rails and gallinules have extraordinarily big feet, well adapted for running over lily pads. "Gallinule" means "little hen," and the Florida gallinule is often called mud hen, or water hen. Its bill is sharp, red except the tip, and rather henlike. It is a poor flyer, swims well, but gets about mostly on foot.

Coots are curious birds, henlike enough to be nicknamed marsh, meadow, mud, water hens. It has more nicknames than any other bird, and it deserves some of them that are descriptive, such as "white bill" and "crow duck." Swimming among a flock of ducks, its dark head and white crow-shaped bill are strikingly conspicuous. It is a round-bodied, slate-colored bird with huge feet and long, separate toes like the rails, but, curiously enough, the toes are expanded into flat lobes. This explains why coots

are such good swimmers. As they rise from the water, and flutter away, they lightly paddle along the surface, or "skitter," so they are called the shuffler, splatter, or blue peter.

17. Plover-shaped birds include two groups apparently very unlike, viz., shore birds (long-legged, slender-toed waders) and long-winged swimmers (web-footed auks, gulls, and terns). Until recently these two groups were described as separate orders. Now they are lumped together and regarded by ornithologists as more alike than had been imagined, probably having sprung, in the very remote past, from the same ancestors.

Shore birds are rather small, with long, pointed wings, short tails, long,

thin legs, and slender toes without webs. They are strong flyers. Many kinds, such as the golden plover, make enormous flights, as we have already noted, during their migrations; on the other hand, the woodcock makes much shorter flights, and migrates merely from its breeding grounds in southern Canada and the northern United States to its winter habitat in the middle states, extending as far south as Florida and Texas.

Woodcocks and snipe have such long probing beaks that they almost seem to be carrying a stick in the mouth (Fig. 26). The plovers have short bills, their nostrils are in grooves, and they mostly have wading habits on seashore or marsh, taking short



Fig. 26. A snipe standing beside its nest. The snipe's bill, which is useful for probing for food, is so long that the birds look as if they were carrying a stick. Snipes are commonly seen in swampy districts, being characterized by their darting zig-zag flight

runs along the ground from one spot to another.

The woodcock's large eyes are set far back upon its head, which would seem to be useful for their protection in probing deeply into the mud after earthworms. It is active only at night. During the breeding season the cocky,

Auks, murres, and puffins are Arctic seabirds which stand erect like the Antarctic penguins and walk clumsily on shore. They are fine swimmers, using their webbed feet as paddles, whereas penguins use theirs only for steering. They feed on fish. Unlike penguins, which nest in holes, they



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Fig. 27. The lovely herring gulls are the most numerous and widespread of gulls. Their diet is not confined to herring alone, almost any kind of small fish being welcome

courting male performs late into the evening an ecstatic, spiral flight, whirling upward a hundred feet or more, twittering musically meanwhile; then, descending slowly like a falling leaf to the ground, he struts about with drooping wings, his little tail perked up.

The female, when flushed, has the strange habit of carrying off a chick between her legs and feet to a place of safety. She lays three or four whitish eggs, thickly spotted with pale red-brown, in a little depression among fallen leaves.

lay their single egg upon a bare rock. One of the parents constantly incubates the egg, and watches over the helpless fledgling.

The terns and gulls are a big family of gray-plumaged birds having their front toes webbed but with hind toe free, and raised above the others. The kittiwake differs from other gulls, however, in lacking the hind toe—hence its name *Rissa tridactyla*, or “three-toed.” Gulls are larger than terns, with the upper bill hooked, not straight and sharp like a tern's. Gulls alight on the water to pick up or cap-

ture their food; terns, with their bills pointing downward mosquito-fashion, hover and pounce directly on it. Gulls' tails are squarish and fan-shaped when spread; terns generally have long, forked tails useful as rudders in their aerial maneuvers.

Many species of gull (such as the herring gull) are white, with blue-gray back and wings. Some gulls (the laughing gull of the Atlantic seacoast and Franklin's of the prairie lakes) have black heads and necks; in many terns only the crown is black. The black tern of the western states is all black in summer, except the blue-gray back and wings.

Gulls and many terns breed in large colonies on ledges overlooking the sea. Other terns lay their eggs in slight hollows scooped out in the sand.

Gulls are useful not only as scavengers which follow ships at sea and the Great Lakes, but also as friends of the farmer. When Utah was being settled, for three years (1848-1850) crops were ruined by a plague of black crickets; finally, flying squadrons of California Gulls appeared, devoured the enemy, and saved the settlers from starvation. Today, in Salt Lake City a monument, surmounted by two gulls in bronze, commemorates the rescue and the settlers' deep appreciation of their avian friends.

18. Members of the pigeon tribe are easily identified by the swollen extremity on their beaks. Usually they have open nostrils and soft skin at the base. The flightless—and now extinct—dodo of Mauritius was a pigeon.

19. The cuckoos have "zygodactyl" feet, with two toes forwards and two backwards as in woodpeckers. The European cuckoo lays its eggs in the nests of other birds, but American cuckoos make their own nests. The Indian koel cuckoo, or rain bird, mimics the mynah's dark plumage and lays its eggs in the mynah's nest. The so-called road runner of Central America is one of the ground cuckoos. It obtains its name from the speed



Fig. 28. The wood pigeon, a member of the extensive pigeon or dove family. The extinct dodo was probably a dove. Pigeons can be distinguished by their beaks, swollen at the tip and covered with soft skin at the base



Fig. 29. A nighthawk's head, showing insect-catching hairs at gape

with which it flies over the ground, as if running rapidly.

20. The parrots often have gorgeous plumage, especially the rosella parakeet and the macaws. Despite their hooked beaks, they are mostly fruit-eating birds. They are arboreal and are good climbers, using their beaks to aid in their climbing. All of them nest in hollow trees. The common little Australian grass parakeet, or budgereegah, now so popular as a cage bird, is often misnamed the "lovebird." The true lovebirds, however, are pretty and affectionate little African parrots about six inches in length, with thick, deep beaks without any ridge along them. The curious hanging parrots of India and Malay, with thin, sharp beaks, are unlike other parrots in that they hang suspended upside down when asleep, or even when resting.

21. Owls are distinguished by the forward direction of their eyes and the discs of feathers around them

which seem to focus the scant twilight of the night on to the pupil. They have hooked beaks, strong claws for gripping their feathered or furred prey, and a dense plumage that is soft and ruffled. Included in this group are the Indian fishing owls and the prairie-burrowing owls.

22. Another group of night birds are the goat-suckers, so-called from an ancient belief that their nocturnal flights among goat herds were for milk and not, as we now know, for

flies. The wide mouth with bristles along the upper jaw is an effective fly trap, and the rapid, swooping flight of the nighthawk on a summer's evening means he is on the hunt for flies.

The nighthawk is a lover of the open country, gregarious, and not afraid of mankind, for whose comfort he is unconsciously engaged. His cousin, the whippoorwill, on the other hand, is a solitary and retiring fellow, fond of the deep, dark woods, not venturing far from their edge, but his oft-repeated "whip-poor-will" is a familiar sound after dark in the eastern United States and Canada. In the southern states, the chuck-will's-widow, a larger bird than the whippoorwill (12 inches instead of 9½ inches in length), but of similar habits, is also heard.

Their feet are so weak that, in perching on a limb or rail, they always sit lengthwise for better support. The chuck-will's-widow totes her young to a place of safety not with her delicate

feet but in her capacious mouth. Large insects are her food, and she is known to have eaten hummingbirds and even sparrows.

Two eggs are laid on the ground by each species, either among the dead leaves or, by the nighthawk, on ledges or the flat roofs of tall buildings.

23. Swifts do not perch like swallows on telephone wires and tree branches, but cling to the sides of vertical surfaces, partly supported by the stiff, naked shafts of their tail feathers. The bill is short, mouth wide, wings long, everything for fly-catching.

Thousands of chimney swifts at migration time swarm about the tops of tall chimneys where they put up for the night. "It seems probable," says Frederick C. Lincoln, an authority on bird migration, "that most of the swifts spend the winter season in the great rain-forest area of the Amazon Valley in Brazil, passing most of the daylight hours high in the air."

The nest of the chimney swift, built of twigs glued together against the inside wall of a chimney, contains four to six pure white eggs. The glue is a salivary gland secretion, of which, in Chinese species, the whole nest is constructed and used by people of that land to make the famous bird's-nest soup. The chimney swift of eastern North America is entirely sooty black. In the high mountains of the western states lives the white-throated swift, all the under parts and rump of which are white.

Hummingbirds, such as the ruby-throated of eastern North America, are like flying jewels. With rapidly vibrating wings, they poise like a hawk moth in front of a flower, dipping the slender beak into the nectar of the cup and darting with great speed from flower to flower.

The extensible tongue is split at the tip, with edges curled up tubelike. The male is slightly smaller than the female, and only he has the brilliant metallic red throat. Her throat is grayish white.

Hummingbirds are found nowhere else than in the western hemisphere, especially in the Tropics. In Anna's hummingbird of California the whole head, except the back and ear region, is brilliant metallic rose. Still other species, the rufous and the black-chinned, are found in the West. Some, such as Rivoli's of the extreme Southwest, feed almost exclusively on insects. These are captured in flight; the bird flies at them, much like a fly-catcher, from its perch.



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Fig. 30. The hummingbird hovers in front of his dinner. A long beak and a long tongue enables him to eat on the wing

The tiny nest of the rubythroat is made of closely packed down from seeds and fern stems and so protectively covered with lichens that it seems a mere knot on a horizontal

limb. In it one may find two pure white eggs.

24. Trogons live in tropical forests where they creep like woodpeckers over the tree, or perch on a branch from which they dart off now and then to seize a fruit or catch an insect. Their short bill is saw-edged and broad at the base; with bristles at the corner of the mouth it is an excellent fly trap.



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Fig. 31. The large beak of the toucan is light and thin, frequently brilliantly colored. Fruit is a large part of the toucan's diet

Even the birds of paradise are hardly more resplendent than the quetzal, a trogon of Central America. Its upper parts, including enormously long tail "coverts" (short feathers covering only the base of the tail in most birds) are iridescent green; below, it is crimson; wings black; tail black and white. Across the wings stretch long bluish green feathers (wing coverts) and, on the head, a crest of delicate green feathers is the finishing touch.

25. Kingfishers are sturdy birds with a strong, sharp beak, small feet with the front toes fused together into a broad, flat sole. The European spe-

cies (Fig. 33) is brilliant green; our belted kingfisher is a bluish gray with belts of white and bluish gray across his throat. Mme. kingfisher has brownish red along her sides.

Perched beside the stream, they watch and dive for fish. The loud, rattling cry of the male warns off intruders from his own special preserve.

A deep burrow, five to fifteen feet, is dug into a bank for a nest. At the inner end of it, five to eight white eggs are laid.

Numerous species are found in Asia and Australia. One of them is the kookaburra, or laughing jackass, which is extremely fond of mice and large insects.

26. The woodpeckers are usually hole-nesting birds with protrusible brushlike tongues to lick insects out of the rotted bark. They also have a hammerhead beak with a perfect shock-absorbing skull so that they can hammer or drum loudly on solid wood as a mating call or hack their nest holes in the trunks of rotten trees. Also, they possess stiff tails that help to support their bodies on the sides of tree trunks, like tripods. To enable them to cling on to the bark, they have two of their toes pointing backward.

The honey guides of Africa are said to attract the attention of visitors and guide them to nests of bees so that they can feed on the grubs when the combs are torn out.

The toucans of Central and South America always attract attention because of their enormously developed, brightly colored beaks. Although, as with the hornbill, their beaks seem to make the birds top-heavy by their size, actually they are remarkably light because they are pitted with air sacs. They are sociable and very noisy.

At their morning and evening gatherings their chattering and screaming can often be heard a mile away. Two white eggs are laid in holes in tall, hollow trees.

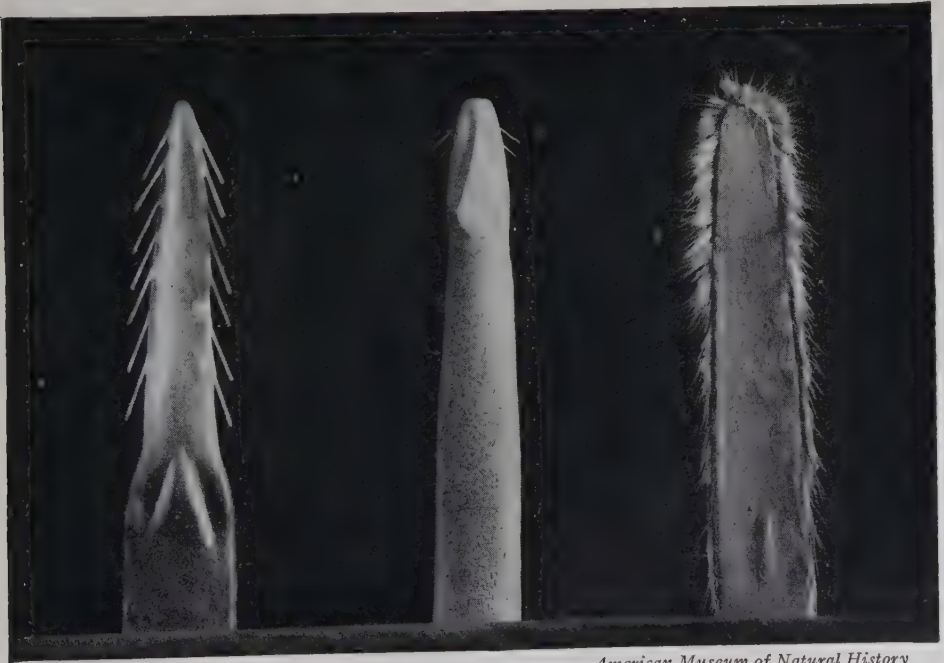
27. The enormous sparrow-form group of the smaller birds includes three divisions of very unequal size: tyrant flycatchers, lyrebirds of Australia, and the great assemblage of songbirds.

Tyrant flycatchers are wholly American. "Flycatchers" in Europe and the Old World are more like thrushes, though their beaks are wide, as in our species, and adapted for catching flying insects. Our species are not all appropriately described as tyrants. Though that term suits the kingbird and the crested flycatcher, it hardly fits the phoebe, the wood

pewee or the least flycatcher. They all dash vigorously and successfully after flies.

They fail to qualify as song birds, though phoebe's cheerful note, the wood pewee's plaintive refrain and the least flycatcher's "che-bec" are agreeable attempts in that direction. The kingbird is remarkably fearless and pugnacious, attacking, in the air, crows and hawks many times its own size.

Lyrebirds of Australia seem somewhat out of place here, when you think of their fowl-like form, large feet and claws for running and scratching, and their erect lyre-shaped tail. All this suggests the peacock or pheasant. The male has a loud, liquid gurgling voice and is a superb mocker and vocalist. No bird excels



American Museum of Natural History

Fig. 32. Three tongues of different species of woodpeckers, enlarged about eight diameters. Reading from left to right they are the tongues of the pileated woodpecker, the flicker, and the sapsucker



Fig. 33. The kingfisher is found in every continent of the world. There are many species of kingfisher and most have a strong, sharp beak (clearly shown above) used for catching fish

him in his elaborate, lively courtship dance. He struts, whirls, quivers, his vibrating tail erect, wings drooping at his sides. Meanwhile, his loud, melodious, complicated song accompanies this vigorous acrobatic performance. Fortunately the Australian government has secured, and can furnish, a sound film reproducing this most marvelous song and dance.

SONGBIRDS

1. Members of the lark family, all active, ground-feeding birds, are characterized by the enormous development of the long hind toe, which seems like a little spur at the rear of the foot.

2. The swallows have wide beaks, long narrow wings and a forked tail. In the chimney swift, often called a swallow, all the toes point forward; it cannot perch. It does not belong to the swallow family although its flight in the air may suggest that it does. Barn swallows build their mud and straw nests on the rafters or beams of barns and sheds; cliff swallows build their retort-shaped nests of mud under the eaves of houses or against cliffs. Sand swallows burrow into sand and gravel banks to make their nests.

3. The crow family includes such dissimilar birds as the raven, and blue jay. Members of this family are recognized by their beak, which is fairly thick and deep, although not hooked, and also by their walking gait. A remarkable member of the crow tribe is the huia bird of New Zealand, the tail feathers of which are worn as a badge of mourning by the Maoris. This bird is curious in that the cock and hen have entirely different beaks. The bill of the male huia is rather short and straight, but



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Fig. 34. Crows, as this one proves, need not be black. The one above is white; sometimes they are of bright colors

that of the female is long, curved, and slender. So great is this difference that early naturalists thought they were entirely different birds. Their beaks are put to different uses. The male bird attacks the decayed timber of trees sometimes to enlarge a hole for its nest, at others to feed on beetle grubs that infest the rotten trees. The female probes the softer hollow parts. The huia is a black bird of the forest, now very rare.

4. Male birds of paradise, which are among the most brilliant birds of the world, have gaudy plumes, proudly displayed in their courtship. This is what is known as a "secondary sexual characteristic," as are the beards of human males, cocks' combs and wattles, stags' antlers, etc. When in captivity, these birds must be isolated after mating, for if left together the cock is almost invariably hen-



Fig. 35. The mischievous jay is a member of the magpie and crow family. Jays, like crows, are noisy birds, often brightly colored, with a peculiar habit of destroying other birds' eggs

pecked to death. As with the peacocks and pheasants, these gaudy plumages are usually confined to the male birds, the females being brown and of a somewhat dowdy appearance.

The bird of paradise is of a very rich, shining brown color with an emerald-green throat and yellow head. Its eyes are yellow and its legs and feet pink. Growing from under the wing on each side of the body are tufts of gorgeous orange-gold feathers. They hang over like golden palms and drape down over the sides, some being from 18 to 24 inches in length. Its habit of suddenly shooting these golden yellow feathers up



American Museum of Natural History

Fig. 37. A collection of plumes of the lesser bird of paradise. These plumes have frequently been the height of fashion as adornments for women's clothing, particularly hats



N.Y. Zoological Society

Fig. 36. Count Salvadori's bird of paradise, like all members of the bird-of-paradise family, comes from New Guinea and the immediately adjacent islands. For all their brilliant plumage, birds of paradise are closely related to the common crows

into the air has a very beautiful effect. It inhabits the East Indies and feeds on fruit and insects. The males gather together in parties of twenty or so to perform curious courtship dances and mock duels, apparently for the entertainment of the hen birds.

5. Closely related to the birds of paradise are the bowerbirds of Australia. Their name arises from the fact that the cocks make a bower or archway of twigs, feathers, etc. Through these arches, which are decorated with shells, bones, and any bright objects that catch their eye, they perform their curious runs. These bowers have nothing whatever to do with nesting, and seem to be erected solely for the amusement of the birds.

6. The titmice are agile little insectivorous birds. They include the

acrobatic little chickadee, or black-capped titmouse. They have short, conical beaks.

7. The nuthatches have a longer and sharper beak; they live on tree trunks and feed on insects and soft-shelled nuts like acorns.

wren tail and activity, and a powerful song, but a thrushlike size and beak. Although they do not have webbed feet, the dippers swim under water and move about the bed of the stream, searching among the stones for the aquatic insects on which they



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Fig. 38. The parent brown thrasher does a thorough job of feeding its young by cramming the food down the young bird's throat

8. The tree creepers, represented by our brown creeper, are small, tree-trunk birds. Their long, slender, curved beaks are used for collecting insects and spiders from the bark. Their long curved claws give them a strong grip, but, unlike nuthatches, they always climb head upward.

9. The wrens are known by their smallness, their comparatively long claws, and curiously upturned little tails. Next to them come the dippers—aquatic birds of swift hill streams. They form a connecting link between the wrens and the thrushes. The dipper, or water ouzel, of the mountains of the western states has the typical

feed. Out of the water they make amusing bowing or curtsying motions.

10. The mockers, or mimic thrushes, are exclusively American and include altogether, on both continents, about 50 species. Besides the mockingbird, brown thrasher, and catbird of the eastern and central states, we have the California thrasher, of deep, grayish brown with buff throat, and three species of thrasher in the southwestern desert country.

Of them all, the mockingbird of the south is the most accomplished vocalist, an ecstatic, brilliant, and beautiful singer of rich variety and exquisite melody. But especially he is

noted for his jocoseness, his repetition of snatches of song of other birds. The brown thrasher has a powerful voice which suggests the mockingbird in a general way, but lacks its beauty. The catbird, of the two, is the better singer, more like the mockingbird in beauty of song and with some mimetic tendencies.

11. The true thrushes include others of our best singers, notably the hermit and wood thrushes. For sheer beauty without display, a rich chant in keeping with the quiet woodland solitudes to which it retires, the hermit is pre-eminent. Similar but slightly less impressive is the rich song of the wood thrush, heard somewhat farther south, and the ringing, flutelike "silver thread" of the veery, slightly down the scale and decreasing in intensity. The vivacious and companionable, yet businesslike, American robin is another representative of the thrush family.

12. Well known among the Old World warblers are the blue-throated, white-throated, and black-capped warblers. These are closely related to the thrushes, even more closely than the American warblers.

13. The unobtrusive little golden-crowned and ruby-crowned kinglets get their names from the almost concealed patch of bright color on their heads, strongly contrasted with their olive-gray coats. The former breeds in northern United States and along the Alleghenies, the latter in Canada north of Quebec; both winter in our southern states.

14. Small flocks of trim, handsome waxwings, or "cherry birds," fly dreamily and with seeming indecision from tree to tree with a sort of sleepy whispering all the while. They are a sleek, grayish brown bird with a sharp



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Fig. 39. The ruby-crowned kinglet, so-named for the bright red patch on its head, is among our best songbirds

crest above a black cheek patch; wings and tail are slaty black, the latter tipped with yellow. The name "waxwing" refers to the scarlet tips of the shafts of the upper wing feathers, which are flattened and prolonged into points which look like red sealing wax. Fruit is only a small part of the food of these birds as well as of the rarer Bohemian waxwing, which breeds far north in British America. Insects, when available, also are included in their menu.

15. The shrikes have a curious little notch in the beak, reminding one of the birds of prey. They catch beetles, small birds, mice, and shrews. In time of plenty they impale their victims on the thorns near their nests to make a larder; hence their name, "butcher bird."

The northern shrike breeds in Alaska and Canada, wintering in



Fig. 40. A young starling. At one time starlings were classed with crows but now they are thought to be nearer thrushes. Notice the rear "perching" claw

southern United States. The loggerhead is found in the Southeast from Louisiana to South Carolina and southern Florida.

16. The starlings are upright walkers, not hoppers. They clack their two mandibles together and produce a strange, rattling background to their cheerful chatter. They occupy during the night great communal roosts in woods, or about city buildings. Flocks travel from a wide area to use the one great central roost.

17. The sunbirds, gorgeously colored little birds of the Old World, seem to take the place of the hummingbirds of the New World in their great activity and in their nectar-loving habits. There is a difference, however, in that the hummingbirds hover on the wing when sipping at

the flowers whereas the sunbirds never seem to hover.

18. The vireos, or greenlets, are exclusively American and mainly tropical. Of the 70 known species, seven or eight are common in the United States. They are small, active, tree-inhabiting insect eaters. In general they are olive-green above, white or yellowish below. It is a curious fact that the eye (iris) color of one species is red, one white; brown in four (warbling, yellow-throated, blue-headed, and Bell's) and brownish red in one (black-capped). Their nests are pendant, and cup-shaped, set in forks of

horizontal twigs.

19. The American wood warblers are a large family of small, lively, arboreal insect eaters, generally of strongly contrasted colors. The length of most of them is around five inches, varying from four and one-quarter in the little blue cerulean warbler to six inches in "Swainson's" and the "bay-breasted." Exceptions to this are the thrushlike ovenbird, slightly over six inches, and the strange yellow-breasted chat, seven and one-half inches, which seem to a novice like an interloper in an otherwise homogeneous group.

Nature, in assigning colors to the warblers, seems to have chosen yellow, olive, black, white, blue, and red, shaken them in a kaleidoscope, and given the resulting combinations to

different species. Not all, of course, would appear in any one bird, but only those giving a harmonious effect among the various juxtaposed patches and streaks.

There is among the warblers some variation in habit; some tend to become creepers, some are especially expert as flycatchers, others, still more original, take to the ground and walk, rather than hop, and persistently wag their tails (ovenbird and water thrush). Few of them are distinguished songsters, but all have their modest, distinctive refrains, casually uttered during their busy hunts for insects, without unnecessary interruption of their work. The Louisiana water thrush, however, is said to be a beautiful singer, and the ovenbird, or golden-crowned thrush, not only calls out repeatedly "we-chee" or "teacher," but has a "flight song" compared by John Burroughs to that of the skylark, "an ecstasy of song, rapid, ringing, lyrical; brief but thrilling; emphatic but musical." Listen for it in early June, especially at twilight.

20. The weaver birds derive their name from the extraordinary communal nests they erect in the trees in Africa, Southeast Asia, and Australia. They closely resemble finches and are small seed-eaters. The English sparrow is a member of this group.

The so-called Java sparrows, one of the commonest of cage birds and a familiar house-nester of the Far East, is not a true sparrow but is one of the weaver birds. It is also called rice bird and paddy bird, because it infests the rice or paddy fields. It is a handsome lavender-gray bird with a black-and-white head and pink beak.

21. The *Icteridae* (meaning yellow) is a large family of American birds,

especially South American, which includes many species peculiar to the United States, such as our bobolink, cowbirds, blackbirds, grackles, meadow larks, and orioles. They are so diverse in appearance and in habits that a general description would not be very helpful. Most of them have long, sharp bills especially adapted for catching insects, but the bobolink's bill is short and conical, almost like that of a sparrow; the cowbirds, a parasite like the European cuckoo, has a conical bill, as is suggested by one of its names, cow bunting. A more descriptive name, however, is brown-headed cow blackbird, which covers its color and association with cattle as it hunts for insects. The red-winged blackbird of the meadows and swamps is also well named. The meadow lark is not a lark, though it lives in the open fields and is brown, streaked with black, like the European skylark. It is a larger bird than that and has a black biblike crescent on its bright-yellow chest; it does not have the distinctive lark's spur, though the toes and claws are long. Quite unlike this bird of the fields are the Baltimore and orchard orioles, which are always in the trees and build pendant nests. The orange and black Baltimore oriole is one of our gayest birds. The grackles, purple or bronzed, rusty, and boat-tail, are blackbirds with long tails. In the Far West Brewer's blackbird, resplendent in glossy violet and bluish gray, replaces the Eastern purple grackle.

22. The tanager family is also American, brilliant in color. They have somewhat conical bills but not as short and cone-shaped as in finches. The tail is short and notched. Adult males are red, with black wings and



U.S. Fish and Wildlife Service

Fig. 41. A pair of green-backed goldfinches, after a drawing by the artist, Louis Agassiz Feurtes

tail, females are olive-green and yellowish, wings grayish brown. We have three species: the "scarlet" of the eastern states; "summer," eastern states south of New Jersey, Ohio, Iowa; "western," yellow and black, wings connected with a broad saddle of black, and head crimson in summer, yellow in winter. These are birds of high trees, though they often nest lower down on horizontal branches. The scarlet tanager's song suggests that of a hoarse robin.

23. The finch family is by far the largest in number of species, about 200 in the United States. It includes, above all, the sparrows, quite too numerous to mention here in detail and superficially much alike in form, size, and, to a considerable extent, color. Each kind, however, has its own in-

dividual habits of nesting, song, and distribution.

Then there are several kinds which we call finches, goldfinch, purple finch, house finch (of the West), pine finch (or siskin), much like the red-poll. There are little finches called buntings, though the word with us has no precise meaning, the indigo and the snow buntings. Larger and with marked individuality are the strikingly black-and-white towhees, including our eastern chewink, named not by the Indians but in their own tongue, so to speak.

All these have simple conical bills of moderate size. There are others, however, in which the bill grows strangely, such as the crossbill, with tips of the beak crossing, one bending to the right, the other to the left. This proves to be no disadvantage in opening cones to get out the seed, and that is what the crossbill regularly does for a living. Another variation in beaks is the extremely large, thick bill of the grosbeaks, fitted for cracking seeds and opening cones.

It is to be regretted that we could not devote a whole chapter to the finches, beginning with the melodious little song sparrow and ending, perhaps, with the canary, putting all our charming native birds, their habits and songs, in between. To any American who has lived in the country a mere list of their names calls up a host of pleasant memories.

None of our song birds better merits our musical interest than the purple finch, song sparrow, and white-throated sparrow of the mountains. None is more beautiful in color than the cardinal and rose-breasted grosbeak, the indigo bunting, and goldfinch, but better still than their colors are their delightful personalities.

CHAPTER 23

MAMMALS

MEMBERS of this highest class of the vertebrates differ from all other animals in that they produce milk, and have more highly developed brain and nervous systems. In respect to the latter, we must admit that birds have even better powers of distant and near vision, keen hearing, and marvelous equilibration. Their memory of places where they have nested and of routes of travel is evidently far superior to man's and to other mammals. These superiorities show that, in these particulars, bird's brains and organs depending on them out-class those of mammals. However, we may still claim that our class, Mammalia, leads the animal commonwealth (or you may still prefer to say "kingdom") in intelligence, inventiveness, and executive behavior.

Mammals are quadrupeds, bipeds, bats, and whales, all of which, as already stated, have milk-producing glands by which their young are nourished.

Milk glands have been evolved from simple oil glands. Sebaceous (oil) glands of microscopic size are universal in this group. They serve to keep the hair sleek and supple; their little ducts open into the sheath around the base of every hair. The small and simple milk-producing glands of the rare, primitive egg-laying mammals (duckbill platypus), however, are highly modified sweat glands. Hair, which is characteristic of mammals generally, is reduced to a few whiskers in adult whales, though before birth the body was covered with hair.

Teeth are characteristic of mammals, and classification of them into different orders is based very largely upon the kind of teeth they have, some for grinding hay, some for tearing flesh, some for chopping up insects and worms, and others for general purposes, as ours are.

Claws can hardly be said to be an exclusive trait of mammals; for birds also have them, but hoofs and nails are typically mammalian—useful for walking over the land, for digging into it, or for protecting the fingers, which are used for many purposes.



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Fig. 1. The hand of a gorilla is not so different from that of his fellow-mammal, man. The nails are a typical mammalian adaptation

All mammals breathe with lungs as birds do. Both are "warm-blooded." In other words their bodies maintain a rather high constant temperature, "homoiothermal" (similar temperature) rather than "poikilothermal" (varied temperature), if you insist on scientific terminology. This constant temperature apparatus of nerves and blood vessels is hardly developed at all in fishes and reptiles; their body temperature depends very much upon that of the surrounding air or water. The mammalian heart is four-chambered, as in birds, but the main artery (aorta) from the heart swings to the left, instead of the right as in birds.

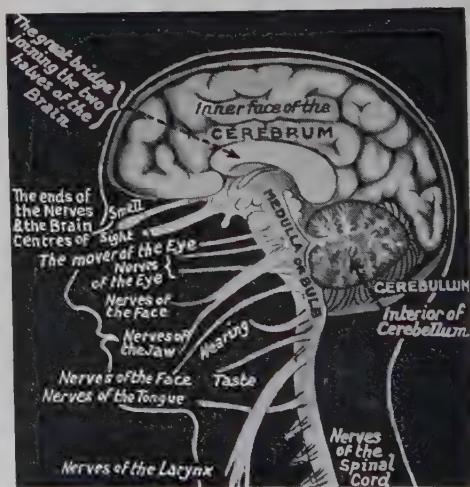
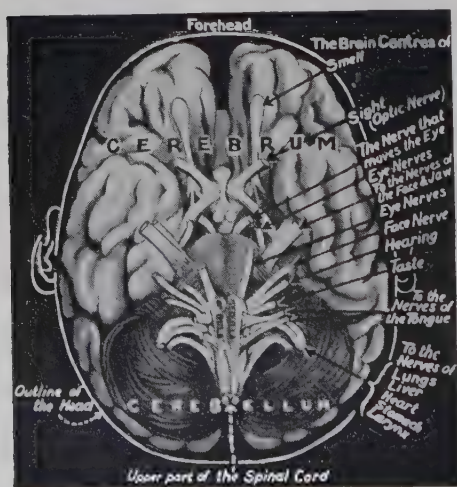
Unlike other vertebrates, the cavity of the body has a muscular partition (diaphragm) stretching across it, separating the chest, or thorax, containing heart and lungs, from the abdomen, where the rest of viscera (liver, stomach, intestines, spleen, kidneys, organs of reproduction) are situated. This diaphragm lies just back of the ribs, to the last pair of which it is attached. It is very useful in breathing, for

when it contracts, it enlarges the cavity of the chest. Mammals, not being fliers, have no such large chest muscles as those of birds, and the breast bone is very small.

THE MAMMALIAN BRAIN

The brain differs from that of the lower vertebrates in the large size of the cerebral hemispheres (upon which memory and intelligence depend) and of the cerebellum, which co-ordinates all the muscular activity and particularly controls equilibration or body balance. Birds, too, have a well-developed cerebellum and big optic lobes, but their cerebral hemispheres are not much better than those of some reptiles.

Comparison of the brains of representatives of the five main classes of vertebrates shows that the brain of each corresponds to its particular way of life. The cerebral hemispheres of fish and frog are small; they are useful in registering smell and taste of food, but memory and initiative are very limited. In the reptile and bird



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Fig. 2. Sectional views of the human brain showing the three main subdivisions

the hemispheres thicken up; their outer wall begins to develop a network of cells and fibers, especially in the bird; memory and initiative are stronger. Then comes the mammal, in which these two traits approach by degrees the mentality attained by man.

The optic lobes, which register vision and control activities depending on that sense, are predominant in every class except the mammal; all depend on their eyes for getting a living. In the mammal, however, though the optic lobes are well developed, they become covered up by the excessive growth of the cerebral hemispheres and divided into four lobes, the two behind registering sounds rather than sights.

The cerebellum shows much variation in the vertebrate series. Its size depends on the muscular activity of the particular animal. If he is rather sluggish and makes no complicated movements, then you find the cerebellum stunted as in the frog. In the reptile, it is better developed; in the bird very well developed, as large as one of the hemispheres, as one would expect from its enormous aerial activities. The bird's cerebellum compared with its own hemispheres is much more conspicuous than in the mammal, in which it gets partly covered by the big hemispheres.

Going a step further and comparing the cat with man, we find the cerebellum in man almost covered by the enormous growth of the cerebral hemispheres. With no discourtesy to the cat, we should point out that man engages in far more extensive and complicated mental activities; while in those abilities depending upon the cerebellum, viz. agility and tree-climbing capacity (muscular co-ordi-



Copyright Black Star by Rapho

Fig. 3. They look as if they would like to say something, but the giraffe is not able to make any vocal sounds

nation and body balance), the cat greatly excels. Man, to be sure, by training, i.e., by using his hemispheres in connection with his cerebellum, may become even more acrobatic than a cat, who is weak in her hemispheres but strong in cerebellar activities.

SPEECH AND SOUNDS

In pure singing capacity, none of the mammals except man can approach the vocal powers of some birds. Only the most highly trained Metropolitan Opera singers, such as Lily Pons and Richard Crooks, can approach or surpass the exquisite natural melodies of the hermit thrush, mocking bird, skylark, nightingale, and the marvelous ringing ecstasy of the Australian lyrebird. Many mammals can roar, bark, mew, yowl, bray, grunt, chatter, and squeak, but elabo-

rate musical songs are almost as scarce as hens' teeth.

The howler monkeys of the South American jungles, in concert, are said to produce the most ear-splitting racket imaginable, but no musical critic has given them a very high rating. The coyote, when he raises his voice in the wilds at the close of day renders a thrilling vocal performance, but so do many of our larger birds.

On the other hand, some animals, such as the giraffe, are thought to have no voice at all.

In his book, *Expression of the Emotions in Man and Animals*, Darwin showed by many examples that man is not the only mammal which expresses its feelings by vocal reactions. Any owner of an intelligent dog knows well its emotional responses of various kinds. But man's languages, even primitive, unwritten languages, are vastly superior to any we have been able to pick up in the rather reticent higher apes or any of the more garrulous mammals.

REPRODUCTION

Mammals, like birds and reptiles, are divided into male and female individuals. The essential organs of the male are the two testes, in which the sperm cells or spermatozoa are formed, and the ducts, which carry sperm cells to the outside. The essential female organs are the two ovaries. At "ovulation" eggs, which in mammals are exceedingly small cells, something like $1/125$ inch in diameter, burst out of the ovary into the cavity of the body and are swept by cilia and muscular action into the funnel-like mouth of the oviduct. Here the egg is fertilized by a spermatozoon, or sperm cell. In all except the lowest mammals, the eggs develop within

the egg tubes of the mother. The embryo soon becomes connected with the wall of the egg tube by membranes and blood vessels called the placenta, through which nourishment from the blood of the mother passes into the separate blood stream of the growing embryo. The time which elapses from the moment of fertilization until birth is called the period of gestation, and this varies greatly in different mammals.

Most mammals in cold climates produce denser furs than those living in regions of milder temperature; in many cases, too, the winter pelage is much heavier than that of the summer. In the ermine weasel, the winter coat is white, the spring and summer suit dark.

In cold regions many mammals, such as bears and woodchucks, hibernate by laying up a store of fat in the autumn and taking a long winter sleep. The heart beats slowly, and fat is converted into nourishment absorbed and circulated by the blood to various parts of the body.

Different squirrels, all of which are more or less active during the winter, vary greatly in their food habits. Chipmunks, or ground squirrels, lay up a store of nuts in their burrows and so they pass the winter indoors, so to speak. Red squirrels, nesting in hollow trees or in the ground, are active all winter except during the coldest weather. They gather great stores of pine and spruce cones, along with corn and other seeds, at the base of a tree or underground shelter. Gray squirrels are still more active during the winter. Their stores of nuts are hidden in many places, usually near their big nests in the high trees, which are much like crows' nests in appearance, or sometimes in hollow trees.

COLORS

The coloring of some mammals is a protective camouflage, making the animal resemble its surroundings and thus escape detection by its enemies. In the process of evolution, those animals not so well camouflaged would be most often caught, while others, escaping, were left to breed. In some cases their colors may enable them more easily to catch their prey. A case in point is the tiger, whose stripes blend with the grasses and with the lights and shades of the jungles where it dwells. The lion's sandy-brown resembles the rocky plains and scrublands that are his haunts. The leopard's rings of spots break up his outline, so that he is not so easily noticed. The zebra's stripes likewise blend with the variegated surfaces of the jungle.

The rabbit's white tail may be a danger signal to show bunnies the way home to the burrow when the mother bolts in time of danger. This, too, is the use of the white rumps of deer and antelopes. An alternative theory suggests that when a rabbit bolts to cover, the eye of its hunter is distracted from the young ones by the bobbing tail. They meanwhile have made their escape or, as in the case of many young deer and hares, they have squatted flat so that their color harmonizes perfectly with their surroundings.

NATURE'S BALANCE

Some creatures, the European meadow mice, for example, increase almost to a swarm when their food is abundant and when the weather suits them. Then their foes, the hawks, owls, weasels, and foxes, also increase and prey on them. Their numbers are reduced to normal again

by disease epidemics. The Bureau of Animal Population at Oxford University in England has discovered much about these sudden increases in the number of meadow mice, for they can be a serious menace to farmers by swarming over his fields and wood-



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Fig. 4. The white tuft of this white-tailed deer fawn is an adaptation which acts as a danger signal to the other members of its family in time of trouble or danger

lands, causing widespread damage. By collecting records from field naturalists over a number of years it has been found that these plagues usually occur in cycles of about every fourth year. They seem to be the result of a natural wave of fertility reaching a peak, then declining, only to rise again.

Probably similar cycles of abundance and scarcity affect other animals over longer periods of years and explain the changing animal populations naturalists have so long observed. One such case is that of the lemmings of Norway. These mouse-like rodents increase out of all proportion to their normal numbers, and, finding there is not sufficient

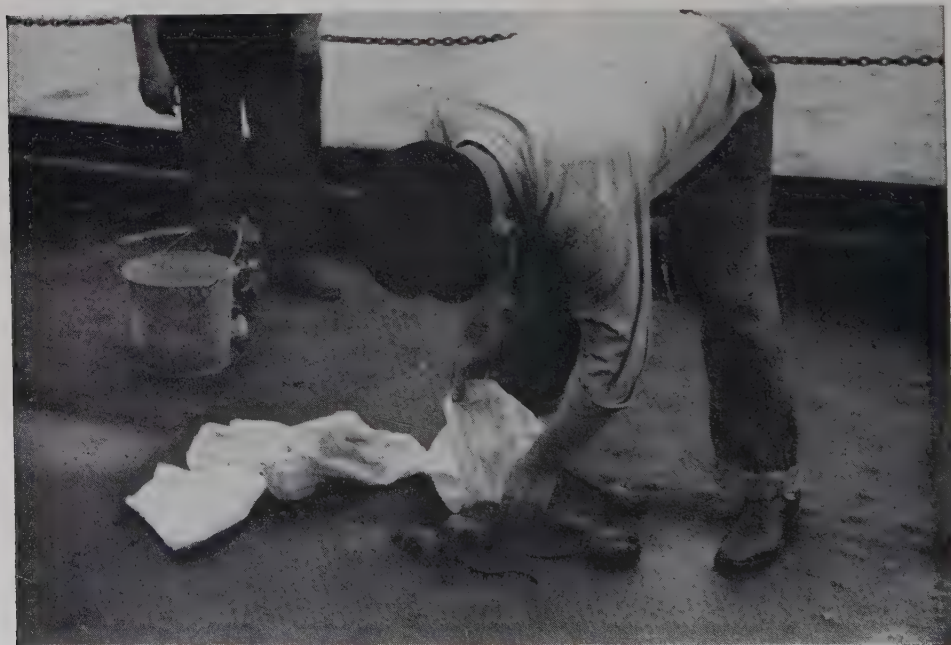
food in their usual haunts, they migrate in hordes across country, ultimately reaching the sea and drowning themselves in a futile attempt to swim across it.

Britain's annual Rat Week at the beginning of November is planned to catch the rats and mice on their return migration from the country, where they have been living in the corn fields and hedges during the summer. In November they move back to the barns, farmyards, and warehouses for the winter.

In the cold weather, when waters are frozen, otters will wander from one lake to another. The flying mammals, bats, do not migrate like the birds, although the big fruit-eating fox bats of Calcutta and other parts

of India, often make long journeys from their sleeping quarters to the scenes of their depredations. They have a wing span of four feet.

The spread of civilization, and especially the coming of automobiles, ships, and other communications of commerce, have so completely upset the balance of nature that we now find many animals living in countries they have never reached previously by any natural migration. This also applies to many plants and insects, and not a few birds. Our rats, for instance, are natives of the Orient and were accidentally transported by commerce to Europe in the fifteenth century and onwards. It is believed that the black rat came first, and that the common gray rat came later. The



U.S. Public Health Service by Rothstein

Fig. 5. Rats were first introduced into this country from the Orient by way of Europe. Here dead rats are being collected from a ship which has been fumigated. The rats will be taken to the quarantine laboratory to be examined for rodent-borne diseases

black rat is naturally a tree rat and often enters so-called "ratproof" warehouses by the roof. On the other hand the brown rat is a ground rat.

It is in the blood of a flea that lives on the black rat that the trypanosome, the germ of the dreaded Bubonic plague, is carried. The unsanitary conditions that encouraged these rats to swarm in Europe in the Middle Ages were the cause of the terrible Black Death. Recent censuses have shown that black rats are increasing in London and in some other places in Europe, but there is little danger of another "Black Death."

DANGERS OF DISLOCATION

If rats increase so abundantly in the United States and Europe, why is it that they do not increase faster in their native lands? The reason is that in their natural haunts they have natural enemies that check any undue increase of their numbers. When they were accidentally brought to this country their natural foes were not brought in with them, so that they were able to increase almost unchecked.

Of course, not every foreign animal or plant can become acclimated to a new country; the majority do not find food, and for some the climate is not suitable. Many may find a new and more acceptable diet, as when the mongoose was introduced into the West Indies to exterminate the rat menace (rats are among their chief prey in Africa and India); they turned to domestic poultry and song birds with serious results.

There are many other mammals living in countries where they are not natives. The fallow deer, a small, spotted deer often kept in parks, and living wild in English forests, are na-

tives of the Mediterranean introduced into England by the Romans. American gray squirrels were introduced into Great Britain during the last century, and are now common.

The earliest record of the rabbit in England is in 1272, and it is believed to have been brought over by William the Conqueror. When the English rabbit was introduced to Australia, it became an overwhelming pest, and increased in size too. English foxes taken to Australia have grown much larger than their ancestors. Pigs, cats, sheep, and horses that escaped from the early settlers have gone wild in New Zealand. The pigs, reverting to their ancestral wild-boar type, have become pests. In Spain a herd of camels, called "feral," or escaped domestic forms, has bred in the wild for generations and become famous. In some of the Welsh and Scottish mountains there are fine herds of wild goats, originally domestic.

Probably New Zealand has suffered more than any other country from the introduction of too many foreign animals. In addition to the Scottish red deer, the big Sambar deer was introduced from India in 1876, and the English fallow deer and the moose in 1901. Ferrets, stoats, and weasels, introduced as pets, escaped and added to the troubles of the farmers. The black-tailed wallaby was brought from Australia in 1870, and in the same year the hedgehog came from England. Other introductions have been the European hare, the house mouse, the Australian phalanger, the Tasmanian sooty opossum, and many birds and plants.

All these instances offer a severe warning of the folly of upsetting nature's "natural balance" among the animals. Excepting in those cases in



New York Zoological Society

Fig. 6. This Virginia opossum and her young are perhaps descended from *Dromatherium* of which two jaw bones have been found in North Carolina

which man can domesticate a creature for his own use, naturalists are generally strongly opposed to the introduction of animals into strange countries, except to be kept in captivity and under control.

ASCENT FROM REPTILES

In the early Mesozoic (Triassic) era, when enormous dinosaur reptiles were stalking about over the sands of what is now the Connecticut Valley in Massachusetts, startling changes of reptiles in the direction of mammals was going on in southeast Africa. There are found the enormously thick (7,000 feet) desposits of sandstones and shales known as the Karroo System, in which the skulls and scattered bones of mammal-like reptiles are found in great abundance. The fossil-bearing beds themselves have an average thickness of 2,000 feet and in places twice that depth.

It is probable that a mighty river like the Nile or the Mississippi during these ages was depositing mud in this huge basin, and that wind-blown sand from surrounding deserts periodically swept into the same areas; thus were formed the almost horizontal strata of shale and sandstone.

These lizard-mammal-like creatures varied in size from that of a mouse to larger than a rhinoceros. Some were herbivorous, vegetarians, but many were carnivorous, with teeth and jaws so like a dog's as to be called "dog-toothed reptiles," or *Cynodontia*.

There were many types of cynodonts, showing various mammalian tendencies in different parts of the skeleton. Their teeth, incisors, canine, and molars, were quite unlike those of modern reptiles; their skulls, again unlike modern reptiles, each had two knobs (condyles) at the base, just as in mammals. Whether they left de-

scendants among present-day African mammals is still unknown.

In North Carolina coal beds of the Triassic period, contemporaneous with South African cynodonts, there have been found two jaw bones of small creatures called *Dromatherium* ("running-beast") supposed to have been a relative and perhaps an ancestor of the opossum, a marsupial, or pouched mammal.

Whether these mammal-like reptiles had scales or hair is still unknown. Some mammals, e.g. the pangolin of India and China are covered with large scales, but it seems unlikely that they are relics of reptilian scales rather than a new development.

EGG-LAYING MAMMALS

Since reptiles are so closely related to birds, as shown by their anatomy

and development, it is not surprising that the most primitive order of mammals has some characters which are birdlike as well as reptilian.

That is true of the egg-laying Mammals of Australia, Tasmania, and New Guinea, viz. the duckbill platypus and echidna. They, like birds and reptiles, lay eggs with a shell which are not very different in size and appearance from those of a small mud turtle (about a half-inch long) and quite unlike the minute eggs of most mammals, which are not laid but are retained in the mother's uterus or egg-tubes. Both these primitive creatures have a single excretory-reproductive opening (cloaca) like birds and reptiles, and unlike mammals.

Both have birdlike beaks and skulls. The echidna, or spiny anteater of New Zealand, is covered above with



Fig. 7. The curious Australian duckmole, or duckbill platypus. It lays eggs like a reptile, suckles its young like a mammal, burrows like a rodent, and has a duck's bill and webbed feet



N.Y. Zoological Society

Fig. 8. The Echidna is a nocturnal, toothless, burrow-dwelling animal with an extensile tongue. It feeds chiefly on ants and similar small insects

short, thick spines and everywhere below with fur of coarse hair. The

long, sticky tongue can be extended far out of the small mouth at the end of a long, slender beak, to catch insects which are then crushed between horny spines on the tongue and roof of the mouth. There are no teeth.

The young one when hatched from the egg is kept for a while in a small pouch on the belly, made by a temporary infolding of the skin on which are the small milk glands. There it is fed by lapping up milk from the wall of the pouch.

The duckbill platypus, like the spiny anteater, has feet adapted for digging, but it is a water animal about 18 inches long with webbed toes. The web extends beyond the toes, giving the foot a very flat appearance, whence its name "platypus." There is a thick, brown underfur, with an outer coat of coarse, flat hairs which cover the entire body.



Fig. 9. The silver-furred phalanger, one of an extensive family of pouched mammals found only in Australia and the far East

Its habits are a little like those of a muskrat, for it constructs a long burrow leading into the water of the pond or stream, with a nest at the upper end well above the water level. It feeds on insects, fresh-water shrimps, and snails, which it gathers into its cheek pouches with the broad, ducklike beak. It dives and can stay under water for as much as five minutes, grubbing along the bottom like a duck. The young have a set of grinding teeth, which are lost and replaced by horny plates; the food is chewed properly before swallowing, quite unlike the bird's method of grinding it in a gizzard.

Two or three eggs are laid in a grass-lined nest in the burrow. They are less than a half-inch long, with a tough shell, and have to be incubated in the nest by the mother. When they hatch, the young lap up the drops of milk from the wet hairs over the mother's simple milk glands, which open beneath the fur. To assist in this process, she lies upon her back and the infants climb over her.

THE MARSUPIALS

The pouched animals are represented in the Americas by opossums. None of the marsupials lay eggs, but the young, born in very immature condition, are put by the mother into a large pouch conveniently situated on the underside of the body.

In Australia and Tasmania, there are many kinds of pouched mammals of very different sizes, anatomical structure, and habits.

Our Virginia opossum is nearly as large as a cat, with a long, scaly, rat-like tail which is prehensile, like a monkey's, and extremely useful in tree climbing. The opossum is nocturnal, and has an abundance of sharp teeth



Smithsonian Institution

Fig. 10. The Tasmanian devil carries its young after birth in a pouch. When adult, it reaches a length of three feet

—incisors, canines, and grinders. The food includes insects, lizards, birds, and birds' eggs. The mother stays in a nest in a hollow tree while her numerous young (about a dozen) are still immature and have to be kept and suckled in her pocket. Later they may be seen in the trees, climbing on her back, with their tails wound around hers. Everyone knows of the "death feint," or "playing possum," of this interesting mammal when it is attacked.

The Tasmanian devil is a badger- or bear-shaped creature with a short tail and ugly disposition, strictly nocturnal in its habits. Other carnivorous marsupials are the Tasmanian zebra-wolf, or pouched dog, the bandicoots (*Perameles*), much like a big, long-eared rat with short forelegs for burrowing and long and strong hind legs for leaping, and a little pouched mole with rudimentary eyes and broad

claws for burrowing. There are no native wild dogs, rats, or moles in the Australian region; their pouched counterfeits are probably all descendants of similar primitive pouched mammalian ancestors which were cut off from the Asiatic mainland ages ago and have developed since then all these specialties in adaptation to different modes of living.

Some are vegetarians, such as the phalangers, which live mostly in trees and have a long prehensile tail. Flying phalangers look like flying squir-

rels, and are able to take great, flying leaps. Some are as large as domestic cats and look like opossums, others like foxes. A peculiar almost tailless one is the Teddy bearish koala with short, wooly fur and hairy ears. It is a slow-moving, nocturnal creature, about two feet long, known in South-eastern Australia as the sloth. It feeds on the eucalyptus leaves.

Wombats are in a family by themselves. They are chunky, almost tailless, woodchuck or bearlike, living in the ground and active only at night.

Finally we must mention the well-known kangaroos of the Australian plains. The hind legs are enormously developed, with the fourth and fifth toes greatly enlarged into a heavy hoof. One species measures five and one-half feet when full grown, besides the enormous, highly muscular tail of about the same length. It jumps 20 feet and more quite easily and is practically a biped, as is man, *homo sapiens* in scientific language.

The smaller species are called wallabys. In the forests of New Guinea live tree kangaroos, which use their front legs, which are provided with large claws, in grasping and climbing the trunks of trees, their hind legs for leaping among the branches.



Fig. 11. The koala bear is found in Southeast Australia, where it is popularly known as the Native Sloth. A marsupial belonging to the wombat family, it is two feet long and a vegetarian

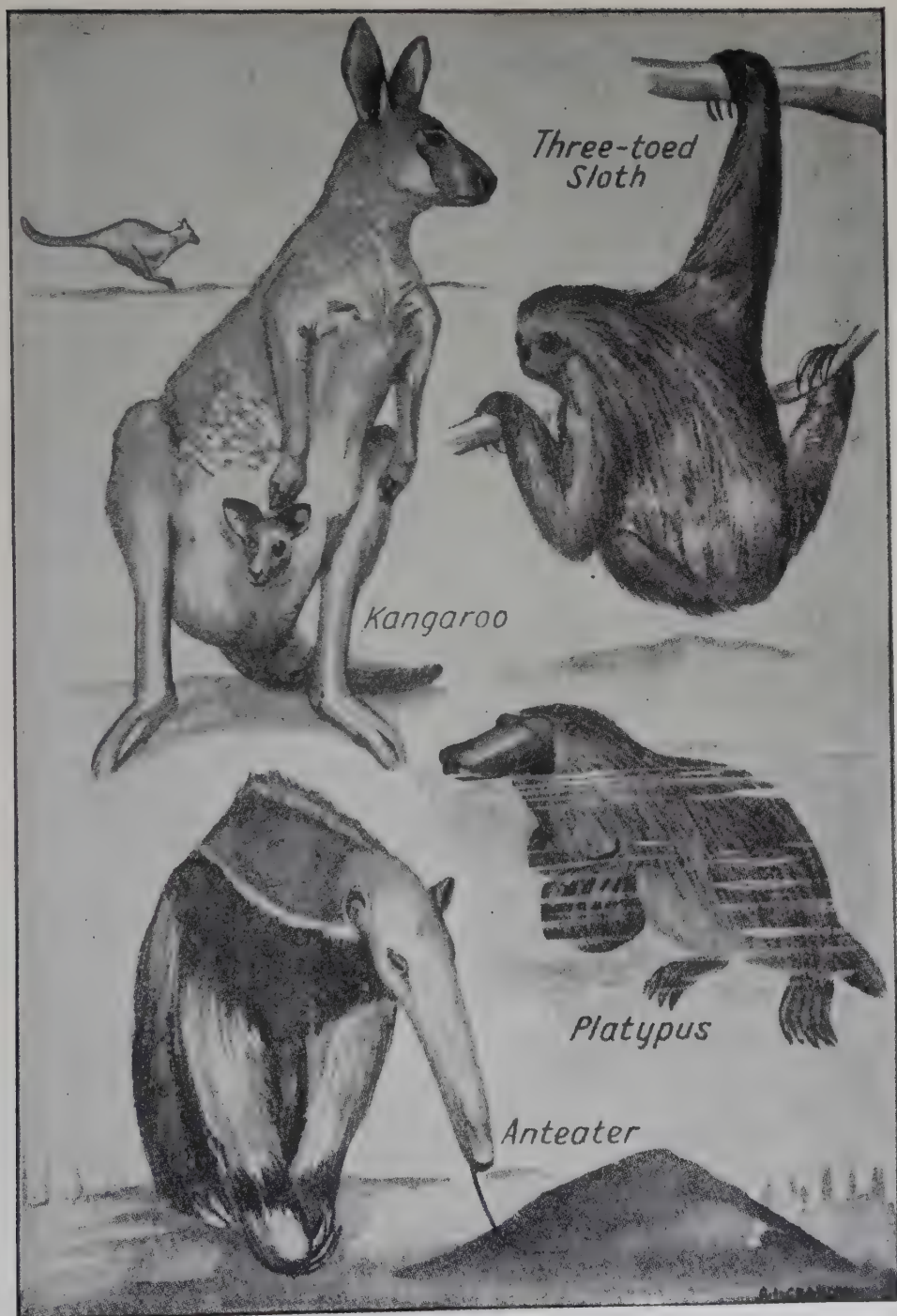


Fig. 12. Some of the curious animals that have survived in Australia

HIGHER MAMMALS

We come now to the orders of mammals which retain their young longer before birth than the marsupials; the embryo being nourished by a well-formed placenta.

The most curious of them all are the so-called *Edentata*, or toothless mammals, sloths, armadillos, and American anteaters. All of them lack front teeth, and the American anteaters have no teeth at all. Nor have the pangolins, or scaly anteaters, of Africa and southeastern Asia. The big armadillos of South America have back teeth. Pangolins and armadillos are anteaters in their own right but are so different anatomically from American edentates that they are honored by being placed in orders of their own.

Insects, and especially ants, are the bill of fare of all these creatures, with the exception of the sloths, which eat leaves. Sloths hang day and night to the underside of a horizontal limb in Central and South American forests. They have long arms and enormous

claws by which they hold on. On their hind feet there are three claws; the front pair has either two, in the "two-toed sloth," or three in the "three-toed" species. A full-grown two-toed sloth is of about the same size as a big Newfoundland dog. Its long, coarse hair grows down toward the middle of the back, so that during the terrific storms of the rainy season, it sheds the rain. Its life seems to be spent wholly in the treetops, where it devotes itself to getting rested, which it never succeeds in doing.

Armadillos, on the other hand, burrow in the ground and dig for insects, especially at night. They are covered with transverse bands of bony plates. The Texas species is called the "nine-banded" because of the nine narrow-jointed bands in the middle of the body, which work like hinges when he rolls himself up into a ball on being attacked. His long ears, narrow snout, short legs, and habit of rooting into the surface of the ground suggest somewhat a small pig.

The tongue is protrusible and sticky; the paws have two long claws used in grubbing for insects and digging burrows, where the armadillo spends most of the daytime.

The young are identical quadruplets, four from the same egg, which breaks up after fertilization into four cells. Or there may be two sets of four.

Three-banded armadillos have only three moveable, jointed transverse bands around their waists. In Argentina have been found the remains of a mammoth type of armadillo which could not bend itself together at all. It is called *Glyptodon*, and its huge shell is in one piece like that of a tortoise. In the same region are found the bones of a giant sloth, *Megathe-*



N.Y. Zoological Society

Fig. 13. The giant armadillo. Note the very large nails with which he burrows into the earth

rium, too huge, apparently, to climb trees. Bones of these extraordinary creatures are on exhibition in many museums.

Anteaters have a long snout, tubular mouth, and an extensible, sticky tongue. The front feet are equipped with large claws which are folded back in walking, so that the animal seems to be walking on its knuckles.

The giant anteater is a huge fellow six feet long, with a large, bushy tail. The silky anteater is an attractive little beast found in Trinidad and northern South America.

Pangolins are found only in Africa and southeastern Asia. Like other anteaters they have large claws, long snout and long, sticky tongue. Covered with an armor of large, overlapping scales, they can roll themselves up into a ball from which it is impossible to unroll them. Some are about six feet long; three feet is the usual length.

Aardvarks, the Boer name for earth-pigs, are nocturnal, burrowing creatures with long donkeylike ears, stout, heavy claws. Their hide, though covered sparsely with hair, is very thick, so they are well protected against the bites of termites and ants.

RODENTS

Rodents have long, chisel-shaped front teeth (incisors), usually two above and two below, adapted for gnawing, and no canines, so that there is a gap between the front and back grinding teeth. Most of them are small, or no larger than a domestic cat.

Hares, rabbits, and pikas differ from other rodents in having an extra pair of much smaller incisors on the upper jaw just back of the two in the middle. The cottontail, or gray rabbit,

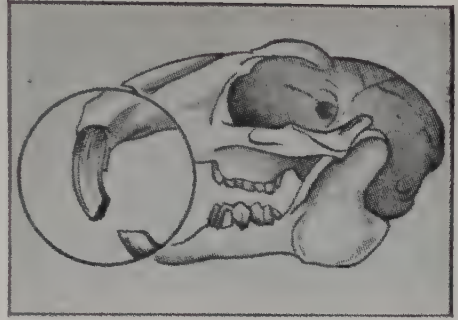


Fig. 14. A hare's skull, showing (enlarged) the sharp and pointed edge of its incisors

never changes color in winter. Its tail is cotton white, as is its belly. On the other hand, the northern hare is brown in summer, white, or whitish, in winter, with a middle band of reddish brown.

In the Far West, from Kansas to Oregon, lives the jack rabbit, or prairie hare, which has very long ears and long legs; it is a famous jumper and runner. In winter it changes color from a yellowish gray to a paler, whitish mixture. It is five inches longer and much heavier than the cottontail rabbit.

Pikas are the little rock rabbits, called "coney" because they live among the rocks. Their habitations are above the timber line, in the western mountains. The coneys of the Bible, "feeble folk" which "made their houses in the rocks," were *Hyrax*, sometimes classified near the hoofed animals but having some rabbitlike characteristics.

Pika looks like a meadow mouse enlarged to the size of a small guinea pig. Like our eastern woodchuck, he has a penetrating whistle. In the winter, he feeds on a store of hay consisting of grass and dried leaves of various sorts.

Besides the three kinds of common American *squirrels*, the gray, red, and chipmunk, or ground squirrel, we have also flying squirrels with a fold of skin stretched between the hind legs and forelegs, by which they glide from one tree to another. They are nocturnal and have large eyes. The long, furry tails of the gray squirrel and larger fox squirrel are also useful as a rudder in their long leaps.

The chipmunks, like gophers and marmots, are burrowers. They are marked with stripes lengthwise on the back and are common in the north-eastern states. Through the central states the thirteen-lined ground squirrel, or striped gopher, is abundant. Some of his thirteen stripes are broken into rows of yellow spots. Black varieties of the red squirrel are not uncommon in certain regions of the Middle West.



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Fig. 15. The chipmunk is a small rodent about six inches in length, excluding its tail. The eastern chipmunk, shown above, has two white stripes on his back as opposed to the western species which has four

Pocket gophers, so-called from their large cheek pouches in which they transport grain and vegetables into their burrows, have huge claws for digging, doubled under when they walk just as in anteaters. They are thickset, muscular creatures with almost no neck, small eyes and ears, splendidly adapted to life underground. Strictly North American in distribution, they range from Illinois, Florida, and the Gulf of Mexico, to the Pacific, and from Saskatchewan to Panama.

Big tropical species, the size of a house rat, do immense damage to sugar cane in Mexico and Central America. In our western states they sometimes burrow along a row of fruit trees, cutting the roots and killing the whole row; or they tunnel beneath rows of potatoes or other root crops devastating as they go.

The woodchuck, known also as ground hog or marmot, is really one of the ground squirrel group, though considering his large size (as big as a 10 pound cat or dog, and much chunkier) and his sluggish temperament, one would not be likely to mistake him for a chipmunk. He is a solitary beast, and often sits upright and motionless at the mouth of his burrow, basking in the sunlight. Wandering out through a clover field, he tramps down the grass and often makes large inroads on vegetables. He grows fat in the autumn and sleeps through the winter.

Prairie dogs are a smaller, western relative of the woodchuck, very social in their habits. They "bark" rather than whistle, which is how they happen to be named "dogs." Their colonies in the Great Plains extend over immense areas, sometimes one or two hundred miles in extent and popu-

lated by many million "dogs." Naturally they are a great nuisance on the Texas cattle ranges. They eat grasshoppers and meat when they can get it, but are mostly vegetarian, cutting and eating all the grass, alfalfa, grain, and other crops near their "towns." Their chief redeeming virtue is their happy sociability.

The beavers are not only sociable but highly industrious; with chisel-edged teeth they fell large trees across streams and construct dams of sticks and mud, making ponds near which they build conical "lodges" several feet high and eight or ten feet across the base. The entrance from the pond is under water. Their feet are well adapted for digging and are webbed; the broad, flat, scaly tail is an excellent propeller, so they are fine swimmers though rather clumsy walkers.

Their range extends over the northern forests of both hemispheres. The American species is larger than the European, and weighs 30 or 40 pounds, sometimes 60 or more.

Their valuable skins were once a staple article of commerce. In frontier



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Fig. 17. Prairie dogs dig burrow homes which sometimes extend in one large colony for nearly two hundred miles

life, a beaver pelt was the unit of value in the exchange of all sorts of commodities. Today, of course, a beaver coat is still an article to be highly prized.

Beavers mate for life, and have from two to five young annually. They feed on bark and twigs, and injure orchards by girdling or felling the trees. Green corn and cornstalks are sometimes added to their regular menu. They work mainly at night, beginning often late in the afternoon, after resting quietly at home during the heat of the day. In the far north, where their ponds are frozen for several months, they lay in a store of sticks of green wood at the bottom of the pond, weighted down with stones and mud. Evidently they are not inclined to sleep all winter like the less industrious bear and woodchuck.

The muskrat is a common American animal not much disturbed by civilization, for it is found everywhere along streams and the shores of ponds, or in marshes. They build houses of



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Fig. 16. The muskrat lives in holes in banks or in home-made houses like earthen igloos. It takes its name from small gland which emit a musk-like odor

roots, stems, and mud in the midst of flooded marshes, five feet wide and three feet high, with a chamber at the top reached by entrances under water. Similar nests are often seen along the banks of ponds and streams, always with the opening under water.



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Fig. 18. The kangaroo rat can stand on its hind legs, which are long and strong, and upon which it can leap in great bounds, much like the kangaroo

They look much like a very large rat and are about the size of a small house cat, thickset, with a flattened, scaly tail, which with their strong, partly webbed hind feet, is useful in swimming. Much more prolific than the beaver, they have from three to five litters annually and from three to thirteen young at a time.

Though vegetarian to a considerable extent, they eat many freshwater clams and snails, sometimes frogs, and rarely fish. Active all winter, they live on stored roots and stems of plants.

Their fur goes by the name of "Hudson seal," or "river mink." It is nearly as dense and fine as that of the beaver. On the eastern shore of Maryland there are very remunerative "fur farms," where large numbers of muskrats are raised for their skins. Their meat is sold as "marsh rabbit" in the markets of Baltimore, Philadelphia, and other eastern cities.

One of the nearest relatives of the muskrat is the field, or meadow, mouse, which is similar to the European field vole. Our species is of about the same size as the common house mouse, but it is chunkier, with short tail, small eyes and ears, round head, short legs, and rather coarse fur.

They make little runways in the grass leading to their burrows, where, in a larger chamber, their winter nest of dried grass is placed. The summer nests are in protected spots on the surface of the ground. In summer they have a mixed vegetable diet; in the fall they gather in grain fields; in the winter they gnaw the tender bark of young trees, often doing much damage.

Much like our field mice are the lemmings of the far north, but they are still plumper and the tail shorter. One of them, the banded lemming, is pure white in winter; in summer it is brown or grayish, with a dark-gray band from nose to haunches.

One of the daintiest of the wild mice is the white-footed, or deer, mouse of the woodlands, which often comes into country houses at the approach of winter. Its prominent black eyes, large ears, and white under parts readily distinguish it from the house mouse.

Among all the numerous kinds of wild rats and mice, none is stranger

than the kangaroo rat of the western deserts. They are neither kangaroos nor rats, but a modification of the small pocket mice of their own localities. Their strong hind legs on which they stand erect, small front legs, and long, bushy tail give them the look of a kangaroo. They have big eyes, are nocturnal and heap up extensive mounds in the midst of which are their burrows.

Well known for his bristling armor of long, sharp-barbed quills, which, mixed with black hair, cover his back and large muscular tail, is the porcupine. In the spruce woods of our mountains and hills he lives in a hollow log or in a cavity among the rocks, feeding chiefly on bark and buds of trees. He is a sluggish creature, most often seen high up in a tree. When attacked by a dog, he bristles up his spines and strikes with his tail. The quills come off easily (though are never shot out, as some have imagined), but once embedded in the dog, their extraction is a painful process because of the recurved barbs.

Scattered sparsely through the woods, porcupines do no great damage. Though never social in their habits, they are sometimes very abundant, in which event they do great damage in girdling and destroying young spruce. Occasionally they stray into orchards and gardens to partake of the settler's fruit and vegetables.

They have from one to four young at a time, and these, well protected by their spines, are soon able to shift for themselves and lead a solitary and uneventful life.

INSECT-EATING MAMMALS

The European hedgehog, though provided with sharp quills like a por-

cupine, is a very different creature. His teeth are small and sharp, adapted for picking up and crushing insects, not for gnawing.

His relatives in this country are the shrews and moles. Shrews are the smallest of our mammals, somewhat mouselike, with sharp noses, short tails, and short, thick, fine fur of the velvety "mole-skin" type. Their feet are short. The common grayish-brown species is smaller, slenderer, and has a longer tail than the dark-colored, short-tailed species. Their small eyes seem to have little use and, like their ears, are buried in the fur.

Their narrow runways in the meadows and swamps are much like those of field mice, but they worm their way through the grass without digging and make little nests of dried grass in which they have many young (six to ten in a litter). The ugly disposition of the shrew is proverbial. They attack mice much larger and stronger than themselves and bite them viciously with their long, sharp teeth.

The star-nosed mole is larger than the shrews and is remarkable for the circlet of delicate feelers around its nose and its broad palms and long claws which adapt it splendidly to digging.

The Oregon mole is a larger species with a beautiful, black, velvety fur, which often has a purplish sheen.

BATS

Bats are the only mammals capable of real flight. Others, such as the flying squirrel, can take long leaps and then glide, but bats are true aerial creatures.

A bat's wings are a wonderful product of evolutionary change. To get



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Fig. 19. This picture of a brown bat shows clearly how the fore limbs have been modified to form wings

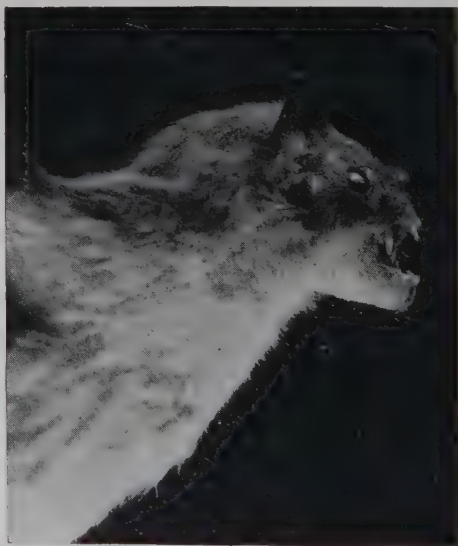
some idea of what has happened, imagine our upper arm to be increased in length by one third, our forearm doubled in length, the fingers lengthened three or four feet beyond that; such would be the bony framework over which would be stretched a membrane made of two layers of skin with numerous small blood vessels and nerves inside of it. The thumb remains of normal size with a strong hook on the end of it. The hind legs are of normal human proportions but the five toes end in long curved claws. The enlargement suggested would give an average human being a wing-spread of about 15 feet. To operate this huge wing expanse, the bat has huge chest muscles.

The eye teeth (canines), which are entirely lacking in a mouse, are long and sharp. The grinders in the insect-eating bats are small and sharp, less sharp in the fruit-eaters.

The latter are found only in the tropics and include some of the large

species called, because of their fox-like faces, flying foxes. Their wing-spread reaches five feet. They hang head down in the trees, by the claws of their hind feet.

The blood-lapping, or vampire, bat of South America is not one of the largest; its wing expanse is 13 or 14 inches, with a body and head three inches long. It feeds by night on blood of wild and domestic animals and birds. Often it attacks man in his sleep without awaking him. This is made possible by the very shallow incision made by the two rapierlike upper front teeth, which slice off only enough skin to produce copious bleeding without pain. The bat then laps, rather than sucks, the blood. The haunches of cattle and the exposed heel of a man are the parts selected



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Fig. 20. The popular belief that the vampire bats can suck blood is a correct belief as well. Its teeth, as may be seen, are especially adapted to cutting the flesh. Some species of vampire bats, however, unlike the *Desmodus rotundus* shown here, do not suck blood

for the operation, which would not be dangerous were it not for the fact that in some parts of the Island of Trinidad, for example, the vampire may transmit the virus of paralytic rabies. Paralysis of the hindquarters of the animal attacked sets in and death may result, though preventive serum inoculations are used to protect cattle and horses which are kept outdoors at night.

Our native species of bats are all useful insect-eaters. They spend the daytime in hanging head down in hollow trees, caves, dark nooks, or attics of buildings, coming out early in the evening to explore the air for insects which they seize in their capacious mouths.

They have only one or two young at a time, which cling to the mother's body until she can safely leave them to hang while she goes scouting for food.

CARNIVORES (FLESH-EATERS)

These "beasts of prey" have long, curved, sharp eyeteeth, called "canine" in honor of the dog, though "feline" would have applied equally well. The back teeth (premolars and molars) have cutting edges, so the whole outfit is adapted for tearing and cutting flesh. The last two molars assist by crushing and grinding. The four or five toes on each foot are well provided with sharp claws, so that the animal is equipped for hunting and capturing prey, which consists largely of vegetarian mammals and of birds. Some of them, as the bears and raccoons, are partly vegetarian, fond of berries and other fruits; the domestic cat and dog have become somewhat omnivorous in their diet.

The order Carnivora is rather sharply divided into the *terrestrial*

families which have their toes separated from one another and the *aquatic* (seals and walruses) with toes united into a flipper.

The members of the cat family (Felidae) vary widely in size, but, if we except the male lion whose big head and shaggy mane make him rather different, they all look much like the domestic cat, which has been a boarder and pet in human households since prehistoric times. They are all remarkable for their agility and cunning, lying in wait for their prey and pouncing upon it with the long, sharp claws of the forefeet and devouring it in their large voracious mouths.

Contemporary with prehistoric man in the caves of Europe was the saber-toothed tiger, remarkable for its huge, knifelike upper incisors, as thin as a pair of daggers, which it appears to have used in striking downward with a slashing blow. The "sabers" projected beyond the lower jaw, in which the two canines were small.

The nearest approach to the domestic cat among our wild felids is the bobcat, or bay lynx, which gives a touch of wild life to the woodland roads and farms not far from well-populated villages. The bobcat looks like an enormous domestic cat with a short, striped tail; the back is rufous brown; below and on the legs are spots of black on a light field.

Nocturnal and shy, it is rarely seen unless it happens to be crossing a road at night and turns for an instant to face the light of an automobile. Yet it not only hunts wild game but occasionally invades poultry yards or kills a lamb. It would not attack man unless badly cornered. Bobcats are found all over the United States and the uplands of Mexico.

In Canada, northern New England, and the northern ranges of the Rockies and Sierra Nevadas, the Canadian lynx is found. It is a third larger than the bay lynx, and has long ear tips, thick legs, and big feet; its bobtail is jet black at the tip, not striped; it is three feet long and weighs 30 pounds or over. The color is grayer, less tawny, than that of the smaller species, and the spots on the body are less conspicuous.

The puma, or cougar, still better known, perhaps, as the panther or mountain lion, is a tawny-brown, almost unspotted, slender beast with a small head and a long tail. It grows to a length of nine feet and weight of 200 pounds. No mammal in America has such an enormous range, extending over the mountains from Patagonia to Quebec and Vancouver. It wanders by night over vast distances in search of game.

Naturally playful and unaggressive to mankind, it often attacks calves, colts, and deer, pouncing suddenly upon them and dashing them to the ground with its heavy weight.

The jaguar, called the tiger, "el tigre," in South America, is still larger and more powerful than the puma. It would be more properly described as a leopard than a tiger, for its deep-yellow color, marked with large rosettes and spots of black, give it a strong resemblance to the African leopard. Its home is especially the tropical jungles and forests, but it still strays into Texas, New Mexico, and Arizona.

It seldom attacks man, but it often kills cattle and chases herds of wild pigs, or peccaries, to pounce on stragglers.

Wolves and foxes are the wild dogs of America. The largest and most

powerful is the gray timber wolf. Once very abundant all over North America, they are now found westward from northern Michigan and southward along the Rockies. Running in packs, as most dog species do, they destroy many deer, cattle, and sheep.

But they are very intelligent and easily domesticated, if trained as pups. Ernest Harold Baynes, an English naturalist, who made his home in the hill country of New Hampshire, raised one to maturity which was as friendly and gentle as any domestic dog, following him on long walks even through city streets. The wolf was somewhat nervous amid the banging noises of the city, and the people they passed, more so. Eventually he had to be killed, much to his master's regret.

Very different in disposition from the timber wolf is the coyote, or prairie wolf, much more nervous and less easily trained. The coyote lives on the prairies and feeds on small mammals, reptiles, birds, and insects, with occasionally poultry and small livestock. It is smaller than the timber wolf, though its color and general appearance are not so very different. Like the fox, it digs a burrow in the ground, and is very prolific, having as many as 14 young in a litter.

One of the most interesting things about the coyote is its evening song. At sunset it raises its head toward the sky, begins with short barks, increasing in tempo and pitch and ending in a long, shrill, ear-piercing call; one hates to call it, as some have done, a squall.

The red fox of America is said by some to be far superior to the English variety in speed, endurance, and cunning. It is the size of a small, slender dog; the long fur is rusty red; the bushy tail is tipped with white.

The gray fox is of about the same size as the red, though somewhat more slender, with longer legs and tail. They are distributed widely through the United States and as far south as Colombia, South America. They nest in hollow trees or holes among rocks, are climbers rather than diggers, and when attacked they quickly seek shelter, instead of leading dogs and hunters on a long chase as does the red fox. For this reason and because the red-fox pelt is much more valuable, they are not much in favor with hunters.

This makes it possible for them to compete with the red fox on even terms, for they produce only three to five pups, or "cubs," in a litter, against eight or nine born in a red-fox den.

The weasels, or martens, are a large family not very popular when alive with anybody except possibly the trappers, but among them are some of our most important fur bearers. Beside those just mentioned, the mink, skunk, badger, and others occur in North America.

The weasels are blood-thirsty, snake-shaped creatures, extraordinarily active animals, able to squirm through a very small hole into a hen house, and more frequently, of course, into the burrows of mice and the nests of birds. They climb trees with agility. Though mostly nocturnal, they hunt also by day. They nest in burrows under rocks, stumps, and logs, or in hollow trees. Usually five or six young, sometimes twice that number, are born in one litter. They follow their mother on her hunting trips, the mother in the lead, and the young trailing about on all sides.

Besides the large weasels, or stoats, there is one dwarf species, the least weasel, similar in habits. Both are cir-

cumpolar; our North American species is said to be the smallest known member of the Carnivora. In winter, both large and small species are white; in summer, brown above, white below. The stoat has a long tail always tipped with black; the least weasel's tail is short, with no black tip.

The mink is of stouter build than any weasel and weighs about two pounds. It is uniformly colored, below as well as above, with rich blackish-brown or yellowish-brown fur, glossy and of finest quality. It does not turn white in winter, and its fur is then in best condition.

Minks are almost aquatic, for they live alongside streams and ponds always in woods and thickets. A nest of grass and leaves lined with feathers and hair is made in a muskrat burrow or under a stump or log. There, in the spring, a litter varying in size from four to twelve is born. The male, especially, is a wanderer, following a river or lake shore long distances, making havoc of chickens and wild birds as he goes. Like the weasel, the mink feeds upon the blood and brains, and then hurries on to the next victim with an insatiable instinct to kill. They eat all sorts of small rodents, also birds that nest on the ground and their eggs. In the water they capture fish, frogs, salamanders, and smaller fry, including freshwater clams.

The keenness of scent of minks and weasels is extraordinary. They themselves, like the skunks, secrete in glands beneath the tail a highly odorous fluid which they eject when attacked, though their muscular spraying apparatus is not as effective, nor the odor quite as offensive, as the skunk's.

The skunk raises its bushy tail and shoots backward as far as ten feet; several discharges may follow in rapid succession if the animal is highly irritated. It is a strongly acid, highly irritating fluid which vaporizes rather slowly, for it is extremely persistent as anyone knows who—or whose dog—gets a dose of it.



Fig. 21. The badger is one of the curious animals like the skunks and the pandas which reverse the usual color design in having the under parts of their fur darker than the upper. This makes them conspicuous in daylight, but they are nocturnal animals

The common skunk is of about the size of a small domestic cat, black with white-striped back and tail. The fur is valuable; it usually is given a pseudonym when on sale. Nocturnal in habit, the skunk wanders slowly about, digging up grubs, eating all kinds of insects, birds and their eggs, snakes, frogs, and whatever meat lurks upon the ground, now and then visiting chicken yards. Its disposition is mild, and it makes a good pet when gently reared from infancy; however, for greater safety, an early operation on the scent gland is indicated.

Another slow-footed relative of the weasels is the American badger of the

western plains and mountains, now almost extinct. It is short-legged, powerfully built, morose, and savage when attacked, like its well-known relative of Great Britain and northern Europe.

Too well known to need much comment is the American black bear. With the Indians he shared the forests before the early settlers came from

Europe. On the fringe of these settlements he has always remained, respected and admired, though sometimes dreaded, for a she-bear with cubs or a male when attacked and cornered may be dangerous; but in general, they retreat from man and quietly go about their own business. This is partly due to the bear's omnivorous habits. Fruits, nuts, green corn, honey, are as much a part of their "balanced" diet as small mammals, including little pigs.

The species is black with brown nose and sometimes a dash of white on the breast. The cinnamon bear of the West is a color phase of the black.

The den is a cave, a shelter of brush, a hollow tree, or a cavity dug in a bank. Here the cubs, which may be three or four, are born. They are fairly helpless at birth; it is a month before their eyes are open and two months before they wander with their mother.

Bears have a keen sense of smell and of hearing but weak eyesight. The cubs make excellent pets, but they rarely, if ever, learn to dance like the European brown bear.

The rarest of bears, if not of all mammals, is the giant panda, or black-eyed *Ailuropus* (cat-foot), found only in extreme western China in a narrow belt running north and south along the border of Tibet. The adult is about as large as a good-sized hog. Its white face with black circles around the eyes gives it a weird expression.

It lives in bamboo thickets, feeds on bamboo stems, and is said to be very lazy. In winter, it hibernates in a hollow tree. The young are sweet-tempered and make charming pets. The first white men to succeed in shooting one were the brothers Theodore and Kermit Roosevelt (1929). In 1935, Mrs. William H. Harkness, of



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Fig. 22. The first giant panda successfully brought alive to this country was a six-weeks old cub, captured in 1935 by Mrs. William H. Harkness. The panda above is a star attraction at the Bronx Zoo in New York



New York Zoological Society

Fig. 23. These Tibetan bear cubs are a subspecies of the European brown bear. They have a somewhat pointed snout, long dark hair, and, when adult, they will weigh between three and four hundred pounds

New York City, bought a six-weeks-old female cub from natives near its habitat, and sold it in Chicago. A year later, three others were trapped by Mr. F. Tangier-Smith of the Field Museum, in Chicago.

Raccoons are bearlike in some respects, doglike in others. Like the bears, their teeth are adapted for chewing fruit and vegetables as well as flesh; that is, the grinding teeth of both are similar. Both walk on the soles of their feet (are plantigrade) rather than on the tips of their toes like dogs. On the other hand, the raccoons have a doglike general appearance and skeleton, and are thought to have descended from primitive dogs. Their faces are especially doglike, or catlike as in the lesser panda, *Ailurus*, or "red cat-bear" of India which has little resemblance to the giant panda.



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Fig. 24. The raccoon is made the object of nocturnal 'coon hunts all over the United States. Although the fur is coarse, it is handsome and valuable

This raccoon lives at altitudes of 6,000 to 11,000 feet in the Himalayas and in the East Indies. It is nocturnal in habit, active in early morning and in the evening, eating herbs, buds, roots, and also eggs and insects. Rather mild in temper, it resembles our own species.

The American raccoon is stoutly built, with long, yellowish-black fur, a long bushy tail marked with dark and light rings, and a black mask across the eye and cheek.

The 'coon is a forest animal, a good tree climber, but also a lover of the shores of streams and ponds, where it finds freshwater clams, frogs, and small fish. But these are only a part of its omnivorous menu, for it captures many mice, birds, reptiles, and insects, and eats its fill of green corn, fruit, and nuts. A curious and admir-



Fig. 25. Two lesser pandas. The lesser panda, which comes from India, is not closely related to the giant panda in spite of the great similarity in superficial appearance; it is in fact, a member of the raccoon family

able instinct is its custom of washing its food before eating. So punctilious is it in performing this rite that, so it is said, even a fish which it has just caught is often washed in the same water before being eaten. This should not be taken to indicate stupidity, however, for raccoons are very intelligent and make excellent pets, remarkable for their inclination to inspect any small object requiring close examination and for their innate neatness. Their dens are in hollow trees, often high above the ground, where they have four to six young.

MARINE FLESH-EATERS

Marine flesh-eaters are large, streamlined mammals which have flipperlike feet instead of separate toes as in the terrestrial carnivores. There are three different families: (1) those with small external ears; (2) walruses; (3) "earless" seals.

The eared seals include sea lions and fur seals, both of which live together in Arctic and Antarctic waters. In the northern Pacific is found the largest species, the Steller's (named after G. W. Steller) sea lion. The males of this mammoth species are twice as large as the females and sometimes weigh 1,500 pounds, three times as heavy as the males of the Alaska fur seal.

Both species are polygamous. In winter the sea lion roams southward to California and Japan, migrating northward in spring to their breeding grounds in the Aleutian, Pribilof, and other North Pacific islands. They pass easily through the most tempestuous seas beating upon the ledges and cliffs of this rugged coast. The roar of the sea-lion bull competes with the deafening din of the booming northern sea.



Fig. 26. The sea lion, one of the few mammals that have returned to live in the sea. It is one of two seals that have external ears

The old bulls guarding their herd of females on the rocks of the breeding grounds are fierce and aggressive, the females are more timorous. One pup is born at a time.

Sea lions are expert swimmers and divers. The California sea lion, the females of which resemble in size the Alaska fur seal, are easily caught and taught to do circus tricks which require agility and skill in balancing.

The Alaska fur seal, which is really a species of sea lion, makes annual migrations similar to those of the true sea lion, wintering as far south as northern California, returning northward past the Aleutian to the small Pribilof Islands, where they breed. The harems established by the belliscose males may consist of 75 cows. Weaker males are beaten off by the big bulls and gather together in groups. These are rounded up by the sealing gangs and driven inland to the killing grounds for their fur.

The walruses are enormous creatures weighing one and one-half to two tons when full grown, with tusks (upper eyeteeth or canines) a foot long. Their mustache of heavy bristles

tons or more in weight. A few of them still live on the Guadalupe Islands of Mexico near San Diego, California; another species on islands in the Pacific Antarctic.



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Fig. 27. The Atlantic Walrus has a muzzle which is abruptly terminated by a tough bristly moustache. There is no external ear, though the orifice is plainly visible just behind and below the eye

is used for straining clams, which they dig out of the mud shoveled up by their tusks.

The seals proper, or earless seals, unlike the sea lion and walrus, have their hind legs turned out flat backward so firmly that they cannot be turned forward when walking on the shore.

The largest of them is the sea elephant, the male of which has a long nose or proboscis capable of being distended, suggesting an elephant's trunk. It is an enormous creature, reaching 18 feet in length, and two

The *harbor seal* is still common along certain parts of the Atlantic coast, in estuaries, harbors, and the mouths of rivers. It is circumpolar, formerly spreading southward in both the Atlantic and Pacific to Japan and Lower California and to the Carolinas. It still breeds, or did recently, on certain islands among the estuaries of Casco Bay, Maine. It is one of the smallest seals, only five or six feet in length. Its skin is covered with short hair and of no market value as fur, though used extensively by the Eskimos for clothing and various pur-

poses. It is spotted, and the species is sometimes called the "leopard seal." It is not polygamous. Small packs gather in early spring on the islands in Maine. The pups are covered with a white, wooly coat and have voices like a crying human child.

The Greenland, or harp, seal spends the summer along the Greenland coast, migrating southward to the Gulf of St. Lawrence in winter and returning in February northward. The young are born in March on floating ice. Greenland is reached in early summer. The adult is piebald, gray with a black head and an irregular black ring stretching along its back.

Among the other mammals which have gone to sea are the whales, or cetaceans, that have grown to be the biggest animals on the earth. The blue whale, or Sibbald's rorqual, sometimes reaches 100 feet in length. Whales have horizontal tails, not vertical ones like fish. This is because the whale is an airbreather with lungs, and in addition to diving to catch its food, it must also be able to rise quickly to the surface to breathe. The fishes need a tail only to force them through the water in pursuit of food.

Porpoises and killer whales have sharp teeth; they catch large fish whole for their food, but the baleen whales, like the big Greenland whale that feeds on small crustaceans, have the mouth cavity draped with huge plates of baleen, the so-called "whale-bone." This acts as a sieve, draining the food after a mouthful of water is squeezed through by the whale pressing its tongue against the roof of its mouth. Although its mouth is so large that a man can well stand upright in it, the throat is so small that it cannot swallow anything larger than a cuttlefish.

As with fishes and minute swimming creatures, the whale does not depend on legs to support its body in the sea; its limbs have developed into flippers and with these it propels itself. When a whale is stranded on the shore, however, it dies from the great weight of its body crushing in its chest, for it has no limbs to support it.

THE LARGEST LAND MAMMAL

The largest terrestrial mammals are the elephants, which are remarkable not only for their large size and superior intelligence but for their peculiar trunk, a cylindrical, muscular extension of the nose, with a grasping tip. Through it, water is sucked into the back of the mouth, so that the elephant drinks from a pool on the ground level without bending his legs. The sensitive muscular tip overlapping the opening of the nostrils is used in handling very small objects and putting food into its mouth. The trunk, twisted around the branches of a tree, exerts an enormous force in breaking off and bringing food to the mouth. Grasses, too, form a large part of its diet.

Its long, curved tusks are strangely modified front (incisor) teeth. It is unnecessary to mention the many purposes for which mankind has used this precious ivory. There are no canine teeth, but there is a full set of heavy grinders.

Of the two living species, the African is the larger, has the larger ears, and is not so easily tamed and used as a beast of burden as is the Indian. Consequently, those we meet at the circus are usually of the gentle, intelligent Asiatic species.

The elephants have on each foot five toes, back of which is a relatively



Fig. 28. Although the zebra's stripes make it conspicuous in captivity, in its natural surroundings of grassy plains and strong sunlight, they make a perfectly designed camouflage

in size and losing one after another of the little-used side toes, till we come to the modern horses with only a single toe. On each side of the base-bone of this toe is a "splintbone," the vestiges of former toes. Occasionally colts are born in which the splintbones tend to develop small hoofs.

Although these ancestors of the horse once roamed over our midwestern plains, they have all become extinct in this country. The wild mustangs were introduced from Europe by the Spaniards, and our present horses have come from Asiatic and

small heel, so they approach the flat-footed (plantigrade) condition found in bears and in man.

ODD-TOED UNGULATES

In this order, the middle finger or toe is larger than the rest and bears the weight of the body. It includes three families: horses, tapirs, and rhinoceroses.

Horses and their kind (asses and zebras) have the tendency to walk on the tip of one toe much more strongly expressed than in tapirs and rhinos. The history of the evolution of the modern horse from the ancient horse-like animals of the Tertiary era is one of the most interesting stories of geology.

Beginning with *Eohippus*, with four hoofed toes on its front feet and a vestige of the fifth, we find a series of small animals gradually increasing

European ancestors.

Zebras are all African, and are not easily tamed and trained. The quagga, formerly found in large herds in South Africa but now extinct, was intermediate in appearance between zebras and asses.

Tapirs are the most primitive of all hoofed mammals. They stand on four toes on the front feet, three behind. They show signs of developing a trunk like an elephant's, and there are piglike tendencies. One species is Malayan; others are found in South and Central America along the banks of streams in the jungle. They are easily tamed, harmless creatures, and deserve to be protected from extinction by the very destructive, and not altogether intelligent, human species.

Rhinoceroses (rhino-nose; ceros-horn) have three toes on each foot, each with a small hoof. The nose

horns are not really horns like those of cattle but compressed and thoroughly hardened masses of hairs growing above nodules on the surface of the skull.

They are huge, fierce creatures, 10 or 12 feet long, covered with thick, loose skin. Especially is this true of the skin in the Indian species, which has only one horn, while the female has only a slight bump on her nose. Their skin is divided into large shield-shaped sections. The African species is somewhat larger and has two large horns. Sight is not keen, but smell and hearing are very acute in the rhinos. Rather excitable and active, they are likely to charge upon any intruder at high speed, faster than

any man can run, though a good horse can outstrip them.

EVEN-TOED UNGULATES

Even-toed hoofed mammals have hoofs on two or four toes. The families of this order are either swinelike mammals or cud-chewers (Ruminantia).

The hippopotamus finds himself classified not as a pig but as very closely related to that family. He was named by the ancient Greeks "river-horse" (hippo-horse; potamos-river) from his aquatic habits, spending the day submerged or sleeping in a marshy forest jungle, active at night, and feeding on grasses and aquatic vegetation. Partly submerged, his



Fig. 29. The hippopotamus, a huge African animal that sometimes reaches a length of twelve feet and a weight of twelve tons. They are found largely in swamps or in marshy forest land and are entirely vegetarian

broad, smooth back, long head, erect ears, and prominent eyes suggest the outlines of a horse, but standing on his stumpy legs with his enormous lower jaw and blunt snout in full view, his piggishness becomes evident. He is 100 per cent African.

The only American representatives of the piglike group are the *peccaries*. The collared peccary of the jungles of Central and South America still roams in herds through the dry, cactus-growing region of southern Texas, New Mexico, and Arizona, though in diminished numbers. Like the European wild boar and pigs, it has a keen sense of smell. When a herd gets a sniff of the fragrance of mankind, it beats a hasty retreat. On the other hand, the peccary emits from a large

gland on its rump a strong, musky odor; hence it is called a musk hog. It feeds on roots, nuts, and fruit, but varies its diet by including such small animals as may come its way.

THE CUD-CHEWERS

The cud-chewers, or ruminants, eat rapidly of grass and leaves which are stored in the first of their four divisions of the stomach, a large pouch, where it is moistened and softened; it then passes in cuds prepared in part two, back to the mouth to be chewed; then it is swallowed into part three, thoroughly mixed with digestive juices and delivered to part four. Naturally the whole alimentary tube in ruminants, since it handles a great quantity of only partly digestible



Fig. 30. The giant pig. Some twenty million years ago huge mammals like this roamed the earth, but they have long since become extinct and have left only their bones as evidence of their existence



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Fig. 31. The bactrian camel (left) and the dromedary are different species of the same genus. The dromedary has one hump instead of two, and is far superior for riding in desert country

food, is much longer than in the flesh-eaters, which swallow food that is much less bulky and more completely digested (made soluble) and absorbed.

The evolution of the camel family, according to plentiful fossil records, took place in large measure in the great plains now included in our west-central states. Early forms were small, the size of a lamb or jack rabbit. Some with a full set of teeth (a primitive character) but with two hoofs on each foot, were succeeded by others which, by degrees, lost the middle upper teeth (missing altogether in cattle) and retained only a pair of side ones and the canines, just as in modern camels and llamas.

In comparatively recent times camels, along with the original wild horses, became extinct in the Southwest, but they had spread to, or evolved in, other continents.

Today the ancient central Asian province, Bactriana, is notable for having the two-humped Asiatic camel named for it. The one-humped camel of the African deserts is the better

beast. It was named the dromedary, or "runner," by the ancient Greeks (from *dromas*=running), a faster and more useful creature, though not much can be said for either its intelligence or its disposition. Its ability to take long marches without food and water is largely due to storage of fat in the hump, which gives it endurance.

The llama and alpaca of South America are domestic representatives, and the guanaco and vicunia wild ones, of the camel tribe. Living at high Andean altitudes and exposed to extreme cold, they have developed thick fur, for which we, and especially Americans of the southern continent, are much indebted to them. Their role in Andean transportation is, of course, of the highest importance.

Only a few representatives of the other cud-chewing families can be mentioned here. The hollow-horned group (Bovidae, named for *Bos*, the bull, father of "bossy") have unbranched horns of a hard material like our finger nails, with a bony core.

They are never shed. In some wild species the female is hornless, as is true of both sexes of some of our domestic cattle.

Sheep, goats, and antelopes, insofar as they have horns, have hollow ones, and all three are cud-chewers.

Buffalo National Park. Unable to migrate to Texas and elsewhere in the south for winter feeding, they have to be provided with hay during the winter.

Along the ranges of the Rockies, just above the timber line, from



Fig. 32. Part of the main herd of bison in Buffalo National Park, Wainwright, Alberta. Bison once roamed the prairies of the Middle West. Some years ago they were almost extinct but they are now protected and are once again increasing rapidly in number

The American bison, or buffalo, which once swarmed over the western plains in immense herds, was slaughtered ruthlessly by Indians and early settlers. When the buffalo was seriously threatened with extinction, various agencies like the American Bison Society sought to establish reservations, such as the Flathead Indian reservation. The wood buffalo of Canada are a somewhat smaller, semi-wild breed. In Alberta, the Canadian government supports a large herd in

northern British Columbia to Colorado, the graceful Rocky Mountain sheep spend the spring and summer. There, in early spring, the ewe, which has narrow, nearly straight horns instead of the huge, curving, fluted horns of the ram, brings forth one or two lambs. Feeding on scanty herbage of all kinds, dashing up and down precipitous slopes with extraordinary agility and precision, they live in places almost inaccessible to man. In winter, heavy snows drive them down

through the forests to the foothills in search of food.

They are brown with white buttocks, and are slightly heavier than the iron gray Stone's Mountain sheep of northern British Columbia. Northward of that, from southern Alaska farther southward, lives a white species named Dall's Mountain sheep.

A clumsier, shaggy, white beast with small, nearly straight, black horns is the Rocky Mountain goat, which lives on the cliffs and ledges along the coast and inland, from southern Alaska to Vancouver and Montana. On those bleak moist heights, the goat thrives on such meager vegetation as the rocks afford. There, in winter and in summer, it carefully picks its way over the precipitous ledges, surviving the worst gales and storms of winter.

The graceful prong-horned antelope of our western plains differs from the numerous and diverse antelopes of Africa (gnus, waterbucks, elands, gazelles, etc.) in having horns which, while hollow as in cattle, are regularly shed in the fall, and also pronged, so representing a step toward the deer. It has no near relatives anywhere.

Like the mountain sheep and several of the deer, it has a conspicuously white rump. Under excitement, the hairs of this patch are erected and form two flowerlike rosettes which serve as a danger signal to other members of the herd.

Formerly they ranged in vast numbers over the Great Plains westward to the Pacific. Now only remnants of these herds remain in scattered regions. Every possible means should be taken to protect them from slaughter and to encourage them to breed, for they are one of the most beautiful



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Fig. 33. A Rocky Mountain sheep. This is a ram, for the ewe has nearly straight horns, rather than the gracefully curved headpiece shown above

as well as the most unique species among the wild mammals of our continent.

DEER

In the bogs of Ireland have been found skeletons of a gigantic elk with broad flat antlers spreading ten or twelve feet, twice a man's height, and rising about the same distance from the ground.

The branching antlers of a deer, unlike the permanent horns of cattle, are the product of a single season's growth even when they have several "points" as in an old male. The illustration of a fallow (yellow-brown) deer shows the antlers in the "velvet." The antler is formed as a bony secretion gradually built up by the blood vessels of the soft, velvety skin which covers, and grows with, the solid, bony interior. When the growth is complete, the velvet dries and is rubbed off.

Except in the caribou, or reindeer, in which both sexes have antlers, it is only in the male that they are developed, a fact closely connected with the secretion of sex hormones into the blood.

The largest of typical deer is the wapiti, a handsome fellow with widely branching, cylindrical horns. Its European cousin is the stag, or red deer.

The American moose corresponds to the elk of the northern forests of Europe and Siberia. It is larger than the European elk; the bull moose weighs sometimes more than 1,400 pounds with a more than six foot spread of his broad, flat antlers. Its huge head and shoulders, short body and long, strong legs well fit the moose for plunging through dense thickets. It wades in summer into the northern lakes and feeds on water plants. In the mating season during the fall, the males lose their usual shyness and often fiercely face and charge a hunter.

The most widely distributed and important North American species is the Virginia, or white-tailed, deer. Ever since the settlement of the eastern states, this has been our most useful game mammal, wary and intelligent enough to protect itself, hardy and prolific enough to maintain a constant population, protected as it is by good State game laws.

It is a brownish gray in winter, rusty red in summer, when, singly or in small groups, it ranges through the woods. In autumn and winter they browse on buds and tender stems of bushes and trees, and on ferns. They gather then in small herds. The rutting season is in October and November in the north, and the one or two, rarely three, fawns are born in May

or June. The fawns have large white spots on a rusty-brown coat, which becomes a dark gray in the fall.

The large-eared, heavier mule deer of the Rocky Mountains, gray with white rump and black-tipped tail, inhabits a more open country. It is less intelligent than the Virginia deer, a high jumper, poor runner, but expert in making steady progress over ledges and rough country.

PRIMATES

In choosing the name "Primate" for the mammalian group to which we belong, the intention was to include in it all of the "firsts," assuming that we are highest of all animals in intelligence, the flower of the animal family, and with us should go the other manlike creatures. The name was chosen before the theory of organic evolution became accepted or even seriously considered. From the point of view of the evolutionist, however, and laying stress on the brain and nervous system, Primates would more properly have been called the "Ultimates."

In many respects, however, we and the apes, monkeys, and lemurs which are with us in this group, are primitive or "generalized." We cannot fly like bats, swim like sea lions, follow trails by scent like dogs, gnaw wood like a beaver, leap like a kangaroo, run like a deer, or climb like a mountain sheep. The abilities of the Primates, and especially man, are rather mediocre in many respects, which is what biologists mean when they say "generalized" or "primitive."

Taken as a whole, the strong point of the "lower" Primates (lemurs and monkeys) is their ability to climb and live in trees. This is especially true of the squirrel-like lemurs of Madagas-



Fig. 34. A fallow deer showing the velvet on its antlers

car, Africa, and Malaysia, and of the American (flat- or broad-nosed) monkeys, many of which have prehensile tails used as a sort of fifth hand in swinging around among the treetops which are their home.

The Old World monkeys and apes, which, like ourselves, have their nostrils and eyes close together, never have prehensile tails, and, as a rule, are not such good climbers. The apes and man, of course, have lost the primitive mammalian tail altogether, and have taken to walking on the ground, more or less erect, on rather flat, bearlike hind feet. There is a strong tendency in this manlike (or anthropoid) group to lose the hair;

the face is regularly bare, and the head often bald.

There is little reason to suppose that the lemurs or the handsome, furry marmosets, primitive monkeys of South America, are exceptionally intelligent. Their brains are smooth, like those of rabbits and squirrels, rather than rolled-up on the surface (convoluted), as in apes and man. This is not a sure sign of "dumbness," though it does indicate limited mental power.

Marmosets have cerebral hemispheres of good size in spite of their smoothness. They are not much larger than squirrels, have bushy, non-prehensile tails, and long claws, instead of nails like other monkeys.



American Museum of Natural History

Fig. 35. A comparison of the hands of a great many anthropoids reveals the fundamental similarity which they all have to one another

Of the three groups of typical South American monkeys, the howlers appear to have the lowest I.Q., or intelligence quotient, though the matter has not been proved experimentally. They make up in vocalization, due to large air sacs at the top of the windpipe which serve as resonators and amplifiers, all that they may lack in brain power and good temper.

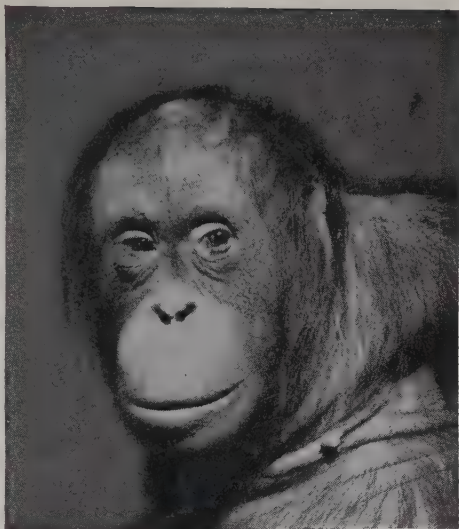
Spider monkeys excel in athletics, having extremely long limbs and tail, but they seem to have made no records in intelligence.

The *Cebus* monkeys, or sapajous, called capuchins from the hoodlike growth of hair above the face, are, on the other hand, easily trained. They are the familiar assistants in the hand-



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Fig. 36. The rhesus monkey is the most common entertainer of all the monkey family to be found in our zoos



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Fig. 37. The orangutan comes from Borneo and Sumatra. Like the chimpanzee, he has been taught to imitate man in matters of dress and food and the like

organ profession. Romanes, in his *Animal Intelligence*, tells of his observations on the mental ability of the brown capuchin, which showed a "tireless spirit of investigation." Having discovered how to unscrew the handle of a hearth brush, he taught himself how to screw it on again. Later, he applied his knowledge to the knob of the fender and other appliances involving the principles of the screw or lever.

On the whole, however, we find that brain evolution proceeded much further in the Old World apes than in any South American monkeys. The monkeys of the Old World, such as the common *Rhesus* monkeys, or macaques, and the baboons, can be quickly distinguished by their dog-like heads and narrow noses. In a Zoo, they are the most numerous and varied of the Primate order. Inter-

mediate between them and the higher apes are the gibbons of southeastern Asia, small apes (about three feet tall) which can walk erect by using their extremely long, strong arms in balancing, but their life is spent chiefly in the trees, where they are acrobats of amazing ability.

Although a large gap exists between the brain and mentality of man and corresponding conditions in the higher apes, it is now generally understood that the two had a common ancestry. About the apes' ancestors we know very little as yet, chiefly because the tropical forests where they lived are highly unfavorable for the preservation of fossil remains. Of man's cave-dwelling, prehistoric ancestors, who fished and buried their dead along the gravelly banks of streams, we are getting more and more information, as will appear in the following section.

Meanwhile, important studies of one of the three sorts of large apes, the chimpanzee, are giving us a more definite conception of what may be going on in the mind of that very, very distant cousin of ours.

The gibbons of Malaysia, abundant, arboreal animals, are receiving attention in reference to the physiology of their reproduction as well as their psychology. In the same general region dwells one of the three most manlike apes, the orangutan, the "wild man of Borneo," and of Sumatra. Unlike his distant relatives in Africa, the chimpanzee and gorilla, who are both brunets, he is more nearly a blond, with reddish-brown hair and yellowish-brown skin. Nearly five feet in height, his arms are extremely long, reaching almost to the ground when he attempts to stand erect. The shoulders and arm muscles are strongly

developed. The legs are shorter than the arms. The bridge of the nose is caved in, and the eyes near together; ears small, mustache and chin whiskers are acquired and well developed at the age of five years. The upper-lip region is wide and prominent, not adding to his beauty.

Orangutans sleep at night in a nest of broken branches high above the ground, and spend the day in the trees eating fruit and twigs.

Chimpanzees are of the same height as oranges; the arms are only slightly longer than the legs. The hair, as in the gorilla, is black. Their big, spreading ears are their most outstanding feature.

Gorillas are huge, powerful creatures, six feet in height with a weight of 500 to 600 pounds in an old male, the trunk being enormous, legs and arms relatively short. The eyes are near together under beetling brows; the lower part of the face and jaws very prominent, chin small and retreating. The ears are small, compared with man's. The flat nose and wide-open nostrils are, from our point of view, decidedly unlovely.

The gorilla is a ground-feeding vegetarian and an enormous eater. His food is mostly tender, low-growing plants and fruits. It is probable that he eats the eggs of birds and reptiles, but little is known as to his animal foods.

Nest building is either on the ground or in low bushes or small trees. By bending over the bushes or small trees and matting them together, comfortable springy mattresses are constructed. But these are temporary affairs. Bands or families continually wander through the forest, primarily in search of satisfactory food supplies for the time being.

CHAPTER 24

CONCLUSIONS: EVOLUTION AND HEREDITY

EVOLUTION means that all animals and plants living today have arisen from simpler forms of life which have become extinct; that today definite processes of hereditary variation are at work, slowly but surely constructing new forms, new species, quite unlike, in most cases, those existing a million years ago. This, in general, is the theory of evolution. It is a theory that is accepted as a fact by all biologists, much as we accept the theory that the earth is spherical. Many lines of evidence confirm it, and, now that the doctrine of special creations of individual species has passed into oblivion along with the earlier idea that the earth is like a vast pancake, there is no opposing theory.

The evidence confirming evolution depends upon (1) the sequences of fossil remains in the earth's strata; (2) the gradual embryonic development of the organs in man and other animals from a simple organless egg; (3) the amazing similarities in anatomical structure among the different animals, such as that between the chimpanzee and man, which can be explained only by descent from identical, simpler ancestors; (4) the occurrence of numerous useless and worse than useless vestigial organs, such as man's vermiform appendix, which are useful in other mammals that are to be regarded as remote kinsfolk of mankind; (5) the evidences from geographical distribution, such as the enormous variation in pouched mammals in Australasia, to be explained by early separation of these great

islands from the mainland and subsequent evolution under isolated conditions; (6) the countless new forms of domestic and laboratory races, which have been and are constantly being produced by skillful selection and hybridization. For example, the extraordinary differences of form and size in dogs and many other domestic animals produced by artificial selection within a relatively recent period of historic time is a slight demonstration of what natural conditions of selective activity during billions of years has evidently accomplished in evolving the vast array of animal forms of which this book has attempted to give, at least, a faint conception.

A PIONEER IN EVOLUTION

An early advocate of the idea of evolution was a French soldier born near Bapaume, northeast of Amiens, the unfortunate region in northern France which several times since has been the scene of terrible fighting. Sent to a garrison on the Mediterranean coast, he became profoundly interested in species of plants near Monaco. Illness put an end to his military career, and he went to Paris. There he studied medicine, wrote a long treatise on the flora of France, and later his epoch-making *Philosophie Zoologique* (1809). At the age of fifty, he began the study of invertebrates, about which very little was then known. Before he died, at the age of eighty-five, he had completed an extensive work in several volumes on this subject. This, in barest out-

line, was the life of Lamarck, or Jean Baptiste de Monet.

Lamarck's work no doubt was largely inspired by the ideas of Buffon, his brilliant predecessor at the museum of natural history and at the Jardin des Plantes. It claimed that species are not incapable of change,



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Fig. 1. Lamarck would have said that this flying squirrel developed the parachute-like folds of skin which join its fore and hind legs from need and usage. This theory has been in many respects greatly modified

as had been supposed, but are constantly being transformed by their own needs and exertions under the various particular conditions which surround them. The snail, needing effective sense organs on its head, continually thrusts forward that part of its body and, by dint of constant use, gradually acquires tentacles. The giraffe, needing a longer neck for browsing on treetops, reaches upward throughout life in one generation after another until finally he has a neck long enough for that particu-

lar activity. Needs and newly acquired habits were regarded as the cause and explanation of new organs, the basis of all progress in organic evolution. Use of organs, or their disuse, determines what they will become in later generations.

Charles Darwin, fifty years later, in 1859, in his *Origin of Species by Means of Natural Selection*, adopted Lamarck's ideas about the inherited effects of use and disuse, but repudiated his speculations about the importance of an animal's *wish* or *will* to do this or that, which Lamarck supposed to be the basis of any new habit. He did not question Lamarck's belief that the effects of long-continued use and of disuse would be inherited. In fact, no one else did, until, as we shall see later, August Weismann in the early 80's showed that characteristics "acquired" through use by any individual are not stamped indelibly, so to speak, upon that individual's offspring.

NATURAL SELECTION

Darwin's greatest contribution to biology, in addition to the collection of an enormous array of facts regarding evolutionary change, was his theory of *natural selection*, or the survival of those individuals best fitted to their surroundings. Darwin showed, as Malthus had done in his *Essay on Population*, that animals and plants tend to reproduce enormously and in geometrical ratio, so that without checks such as famine and pestilence, overproduction of individuals is bound to occur in every species. He argued accordingly that, under natural conditions, there must be intense competition for food and a livelihood in every generation among the members of any species, and that in this

competition, or "struggle for existence," only the fittest, those best adjusted to their surroundings, would survive and transmit their particular useful qualities to their offspring.

This implies, as you must see, some important assumptions, viz., that in any generation there would be plenty of slight inheritable variations in an individual's different organs. Many of these variations might be unfit to enable that individual to meet the shocks of life, hence he would die without leaving offspring. But, on the other hand, the "fittest" would survive and pass on to their offspring their superior traits, their highly useful or "adaptive" characteristics. In this way, nature, so to speak, *selects* the best and eliminates the worst, just as the breeder of animals or plants regularly does in trying to improve the stock under his care. Natural selection is thus comparable to a husbandman's artificial selection.

This is essentially the theory, and the only theory, by which today we try to explain the marvelous adaptation of organisms to their environment. It needs certain qualifications unsuspected by Darwin, though in the main it stands unchallenged.

But Darwin's theory of natural selection went further than that. He brought out the fact that animals and plants are constantly migrating to new places, new environments, to which they would make by natural selection new adjustments, and also in any one region profound changes in external conditions, such as climate, occur from age to age, involving new types of organs useful for living under the new conditions. Aquatic animals are thus forced to get their living on land, or land animals in the sea, in order to survive.

So today we find the world stocked and peopled with an infinite variety of species and varieties of plants and animals adapted more or less well to every conceivable terrestrial and aquatic habitat. Nor should we forget that in the strata of the earth's surface are buried the remains of a few of an infinite number of forms which have ceased to exist, species, genera, families, and even whole



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Fig. 2. The otter is an example of an animal which through natural selection has adjusted itself to living both in the water and on the land

orders, which are now totally extinct. All these multitudes of plant and animal forms past and present were created by evolutionary processes.

The next notable advancement in the theory of evolution after Darwin came twenty-four years later, in 1883, when August Weismann challenged Lamarck's and Darwin's assumption that characteristics produced mainly by an animal's own exertions or, on

the other hand, by constant disuse of any part of the body, would be inherited.

WEISMANN'S CONTRIBUTION

Until Weismann's first essay on heredity came out in 1883, practically no one had questioned the accepted belief that a blacksmith's sons would have more muscular arms because the father had enormously developed his own by wielding a sledge hammer; that the daughters and sons of an assiduous mathematician would be all the keener at solving problems because the father, mother, or both, had devoted themselves to intense intellectual effort and the acquirement of extraordinary power as mathematicians.

Such parental acquisitions as these were called "acquired characters," traits of environmental, rather than genetic or internal, origin, the inheritance of which Weismann claimed had never been proved either by direct observation or by experiment. He cited "the frequently quoted instance of the cow which lost its left horn from suppuration, induced by some unknown cause, which afterwards produced two calves with a rudimentary left horn in each case." Regarding this case he said: "But as Hensen [*Physiology of Reproduction*] has rightly remarked, the loss of the cow's horn may have arisen from a congenital malformation, which would certainly be transmitted, but which is not an acquired character."

Weismann, himself, tried the experiment of cutting off tails in mice for fifty successive generations to see whether, as a result, mice without tails would eventually be produced; none were. The reason for the non-inheritance of such mutilations and

other "acquired" characters, according to Weismann, was that the reproductive cells in the ovary and testis, which must be changed in order to have any hereditary effect, are isolated to such a degree from the various other parts of the body that even profound changes in these other parts can have no specific effect on the reproductive or germ cells, nor on the offspring which they produce.

New variations arise, Weismann claimed, by union of the germ cells of two different parents resulting in new combinations of the qualities of both. Variation thus is from within, not from without, as Lamarck and others had assumed. Given these variations, natural selection would act effectively in producing evolutionary change. Weismann, indeed, strongly upheld Darwin's theory of natural selection. He was also one of the first biologists to maintain that heredity must depend solely upon chromosomes within the nuclei of the germ cells, and that the individual particles of which these chromosomes are composed are responsible for the development of definite qualities in the offspring. Such supposed particles he named "determinants."

About this idea that the tiny threads called chromosomes are responsible for the variations that have given rise to all the marvelous array of plant and animal life, Weismann built an elaborate speculative "germ-plasm" theory as to the structure of chromosomes, which has been superseded recently by direct observations of much more exact nature. He and other contemporary students of the cell, however, made it evident that the microscope would reveal many things about the source of variations and the evolution of the living world;

that plants and animals, though immensely diversified in appearance are strangely alike in the processes of cell life and principles of heredity.

Any body, plant or animal, is studded with minute spheres called cell nuclei. If they were illuminated and the body were transparent, they would shine like an immense constellation of infinitely small stars. During growth, these stars always multiply, for when each cell divides, its nucleus divides also.

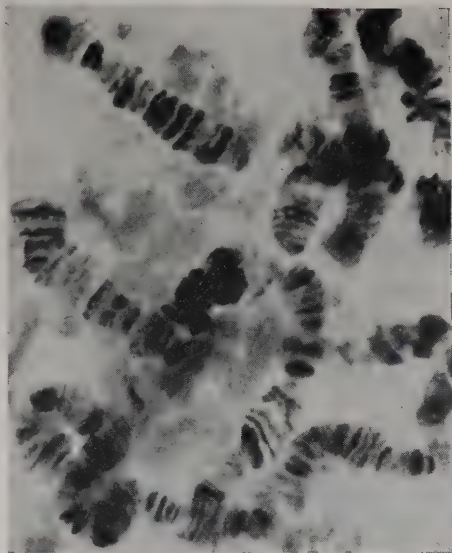
WHAT ARE CHROMOSOMES

Division of a nucleus involves the division of the chromosomes within it, the bearers of the hereditary tendencies. A chromosome (colored-body) is a translucent, uncolored rod



Copyright Black Star by Goro

Fig. 3. This is a "featherless chicken," the laboratory result of scientific selection rather than natural selection. Several generations of the original fowl's descendants have been raised with the same nude result



Science Service

Fig. 4. These thick, somewhat snaky objects are the chromosomes, which contain the heredity-bearing genes which determine the traits of the offspring

or thread, easily stained by certain dyes which are used to make it clearly visible in thin sections of body tissues. Properly stained, the chromosomes naturally become "colored" rods or threads. They are the important nuclear substances, surrounded by soft, living material of less permanent nature.

When cells are "resting," that is, not actively dividing, a spherical "nuclear membrane" encloses the chromosomes and other nuclear substance; outside of the nuclear membrane is other living material, here called "cytoplasm" to distinguish it from that of the nucleus.

But when cells stop resting and divide, something very interesting happens to the chromosomes. The nuclear membrane dissolves, and the chromosomes arrange themselves in a circle around the middle of a long,

spindle-shaped figure made of very delicate strands of the less-permanent nuclear material surrounded by cytoplasm. In an animal cell, one can usually see—at the ends of a spindle—star-shaped radiations around a central body, or “centrosome,” like iron filings influenced by the poles of a magnet. These asters and centrosomes, when present, arise by division at the beginning of a cell division and repel each other.

But the important fact for us now is that the chromosomes are present in a definite and even number characteristic of each species. In human cells there are 48, cat 36, dog 22, housefly 12, pea 14, onion 16, pine tree 24. As will appear later, these are double numbers; of our 48 chromosomes, 24 in every body cell were the mother’s contribution (from the egg), 24 were the father’s (from the spermatozoon), which somehow contained a “reduced” or half-number.

In ordinary growth by cell division, all of the chromosomes split lengthwise and migrate towards the ends of the spindle, so that when the cell divides to form two young cells, which we may call “daughter cells,” each of the latter has a full number of chromosomes.

THE EMBRYO GROWS

Now the one-cell embryo of any animal or plant begins life with this full outfit of chromosomes, for the egg has a sample of all the mother’s and the spermatozoon a sample of all the father’s. This one-cell embryo loses no time before becoming a two-cell and, as we have seen, this cell-division process involves an even distribution to the two cells of samples of all chromosomes from both sides of the house, that is, an equal

division of hereditary tendencies in the offspring.

The two cells then divide into four, with the same equal distribution of hereditary material; and, as the body is gradually built up into the 8-, 16-, 32-cell and later stages by a long series of cell divisions, the same distribution of hereditary material among all the cells of the body is accomplished. These cells vary greatly in size and shape, but their nuclear contents, the chromosomes, maintain the same number.

Weismann, as well as other nineteenth century students of the cell, knew all this and realized that the precise distribution of chromosomes throughout the body was of vast importance in controlling growth of every part, though his conception of the manner of this control has proved erroneous. He further realized that to keep the number of chromosomes constant in any species and to avoid their constant doubling whenever fertilization of an egg by a sperm cell occurs, there must be a reduction in chromosome number in germ cells just previous to their union in the process of fertilization. These are facts which have survived the elaborate speculative theories of Weismann and his contemporaries as to heredity and chromosomes.

MENDEL’S LAW

All at once, at the opening of the twentieth century, a new era in the history of biology began with the re-discovery of Mendel’s law of heredity. The experiments and conclusions of Mendel were apparently unknown to Weismann, though published at Brünn in 1865, nearly 20 years before Weismann’s essays appeared. For sixteen years more, until 1900, the record

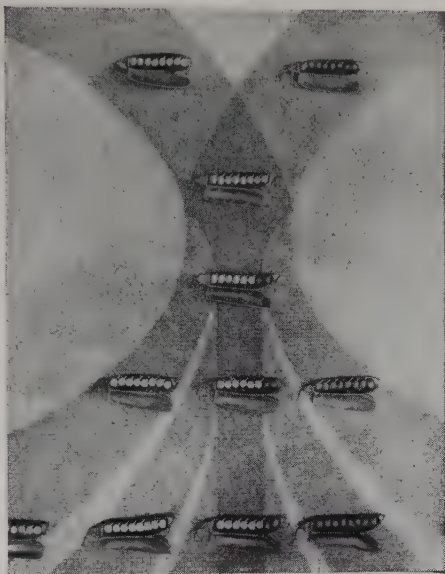
of Mendel's pea-breeding experiments and his keen conclusions drawn from them, remained unappreciated and almost unnoticed in the proceedings of the local scientific society at Brünn.

Mendel was an Augustinian monk who carried on his experiments while teaching natural science at the technical high school (Realschule) at Brünn, corresponding meanwhile with his former instructor in botany at Vienna, Professor Nägeli, who likewise failed to recognize the significance of Mendel's discovery.

Briefly stated, it is the law of "splitting of hybrids," that when two plants unlike in a certain respect, such as long vine versus short, are crossed, the result is not a blend which stays blended in the next generation, as had been generally supposed, but one which splits or segregates into the original unlike forms. Often in the first generation of the cross, the "hybrids" take after one of the two parents exclusively; this parent and its characteristic would then be "dominant," the other "recessive." Tallness (long pea vine) was found to be dominant to dwarfness (short vine).

Seeds from hybrid tall plants, however, when fertilized by the hybrid pollen from the same plant, could not be depended on to grow into tall plants; in fact a numerical count showed that while three-fourths of them did grow tall, one-fourth remained dwarf. And if the flowers of the tall hybrids were opened very early and fertilized with pollen from dwarf plants, the resulting seeds grew into tall or into dwarf plants in equal numbers.

Mendel reasoned that hybrids, or mixed individuals, "split" by producing germ cells of two sorts in equal proportions; recessives always pro-



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Fig. 5. The common garden pea was used by Mendel in his experiments on heredity. At top are the yellow and green varieties which are crossed and produce the dominant yellow. In the following generation, produced by the second generation with one another, the recessive green makes its appearance. If the plants of these green seeds are bred together, green seeds always result as only the recessive green is present. If yellow seeds are so bred, one-third will be pure yellow, the remainder both yellow and green

duce recessive germ cells and so do pure dominants. Accordingly, in the second experiment just mentioned, the hybrid flower must have produced just as many "tall" ovules as "dwarf," 50 per cent of each, for they were all fertilized with recessive "dwarf" pollen which would not visibly affect the offspring.

MENDEL'S LAW IN PRACTICE

Assuming then that a hybrid plant always produces in each sex (ovules

and pollen) two sorts of germ cells in equal numbers in respect to any pair of contrasted characteristics, it is easy to see why the 75:25 ratio came about in the former example. Let us take first that half of the ovules which contain the tallness-producing factor. They would be fertilized by pollen assumed to be pure tall and pure dwarf in equal proportion. Then consider the dwarf ovules. They likewise would have equal chances of meeting tall or dwarf pollen-grains. The net result would be represented simply as

Pure tall
25 per cent

Mixed tall
25 per cent

Mixed tall
25 per cent

Pure dwarf
25 per cent

which means that three would grow tall and one would remain dwarf. The larger the number of individuals, the closer would be the result to these proportions.

Mendel tested the inheritance of six other pairs of contrasted characteristics of plant and seed, such as colored flowers vs. white, smooth seed vs. wrinkled. In each case he got similar numerical results. The qualities always emerged in definite clear-cut proportions. In the offspring of mixed or hybrid plants there was a return to pure types along with an equal number of hybrids. Earlier hybridizers of plants had failed to get these results chiefly because they had tried to keep track of too many characters at once, and so got jumbled results. Mendel did combine observations on two or three pairs of contrasted characters at once but never more than that, and discovered that the same proportions held for each contrasted pair, even in these slightly more complicated combinations of the traits being studied.

MUTATIONS

His rediscovered principles fitted admirably into the mutation theory of the late Hugo De Vries of Amsterdam, one of the three botanists who independently rediscovered and tested Mendel's results. The idea advanced by De Vries was that new varieties, or "elementary species," arise not by the painfully slow accumulation of minute inheritable variations generation after generation, as Darwin had supposed, but by sudden jumps, i.e., the appearance of offspring in various respects unlike the

parents, involving a rapid change or "mutation." It is acknowledged nowadays that De Vries was breeding some very complicated hybrids, in the evening primroses which furnished his apparently true-breeding mutations, but it soon became apparent that the contrasted characters in the common garden pea with which Mendel had worked might justly be called mutations which sometime or other arose by spontaneous changes in the germ cells.

Mutations of this sort turned out to be very common in both animals and plants, and their inheritance has been found by numerous investigations to conform to Mendel's laws of segregation of unit factors (or genes, the pure "determinants," Weismann might have called them) which separate from each other in the germ cells, reunite in the offspring, and control the development within it of the characters which they represent.

As a rule these mutations are recessives which suddenly appear (or have in the past originated) in wild

stock which is usually dominant in respect to these recessives. Albinos, occurring in many mammals, are an example of one of the most common of them. White mice are recessive, just as are dwarf pea vines. Crossed with wild gray mice, the offspring are all gray, but these, mated together, produce 75 per cent gray and 25 per cent white young. This is because the hybrid grays produce two sorts of germ cells, potentially colored or white, in equal numbers. To prove this, mate a supposed hybrid gray with a white to see what happens. If it produces two kinds equally, viz., Cc , then when fertilized only by c there should be just as many gray, Cc , hybrid offspring as cc , or albino, and such is found to be the case. If, on the other hand, they were pure CC (one kind of germ cell) then, mated to a cc albino, *all* the offspring are Cc , or colored hybrids.

It becomes obvious that in respect to Mendelian inheritance, characters are in pairs represented in germ cells by factors (or genes) responsible for their development in the resulting individual. Now, since Weismann's time it has been found that chromosomes always occur in pairs, which is why in each species we find an even, rather than an odd number.

CHROMOSOME REDUCTION

It will be remembered that he found that mature germ cells always contain half the number of chromosomes characteristic of that particular species, so that in germ-cell formation a reduction division must occur. Now if the pairs of Mendelian factors are really in chromosomes and chromosomes are in pairs, this should afford an explanation of why mixed or hybrid individuals produce two sorts of

germ cells in equal numbers in respect to any pair of contrasted characters.

As an observed fact, in germ cells just previous to the reducing division in both animals and plants, the chromosomes line up against one another in pairs, and, in the reduction division, simply break away from each other to go each into one of the two resulting germ cells, without the usual longitudinal splitting. Thus the total number of chromosomes in the mature germ cells is reduced to one half the characteristic number, and, simultaneously, a hybrid produces two sorts of germ cells in equal proportions.

Now if at that time a hybrid gray mouse has a pair of chromosomes in which a "gene," or Mendelian "factor," for albinism, c , occurs at a certain point in one chromosome, while in the chromosome lined up against it there is the "factor" for its opposite, viz., dark color, C , then it is evident that when reduction occurs two kinds of germ cells would result, and just as many of one kind as of the other. These "factors" are now usually called "genes" and they are considered to be invisible particles of chromosomal matter. The theory is that, sometime in the past, a mutation occurred at the c point in one or both of this particular pair of chromosomes, transmuting C , a color-forming gene, into c , albino-determining. Since recessives always produce only recessive germ cells, this pair of chromosomes in a white mouse would be represented in all cells of the body as cc , and it is the presence of the double cc which keeps any dark color from forming in the fur of the mouse.

Mice were among the first of the many kinds of mammals to have their heredity investigated. Besides the re-

cessive albinism, five other pairs of contrasted color factors (or genes) have been studied; these can be represented in one mouse in all sorts of combinations of the six pairs, making 32 visibly different color varieties of the common house mouse. A curious fact is that an albino, recessive for the color-producing factor, may be potentially black or brown, dark or pale, black-eyed or pink-eyed, self-colored or spotted. Its real nature (among these various alternatives) is easily revealed by crossing it with a multiple-recessive animal, viz., with a pink-eyed, spotted, dilute (pale), brown mouse, which has no dominant factors to cover up those concealed in its albino mate. The concealed potential dominant colors show up immediately in the offspring of the first generation bred of these two.



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Fig. 6. A yellow rat mated with black-hooded individuals, a tame race which breeds true, produces gray offspring like common wild rats. The grandchildren, however, are of the eight varieties seen in the bottom row

THE WALTZING RECESSIVE

Waltzing (vs. straight-running) is another recessive. If you should cross a black-and-white (spotted) waltzer with an albino, the offspring may all be black, unspotted runners, but in the next generation 25 per cent would waltz, 75 per cent would run; 25 per cent would be albinos, 75 per cent colored.

Ordinarily, double hybrids mated together give a 3:1 ratio in respect to *both* pairs of factors so that four kinds of individuals appear in the offspring in the ratio: 9:3:3:1; i.e., 9 showing *both* dominants, 3 *one* dominant, 3 the *other* dominant, and one double-recessive. For example, 9 *plain-black, runners*; 3 *plain-black, waltzers*; 3 spotted, *runners*; 1 spotted, waltzer; always provided the number bred is large enough to show clearly the possibilities.

When factors are freely assorted at random, they give the above ratio, but in many cases the pairs tend to stick together or to be "linked." This linkage was discovered by Thomas H. Morgan (Nobel prize, 1933) and his colleagues to be due to the association of linked genes within a single pair of chromosomes. In the little pomace, or vinegar, fly, *Drosophila*, four groups of numerous linked genes were found, corresponding exactly to the four pairs of chromosomes in which they are located. The study of the location of these genes in these chromosomes, which is now described in every textbook of genetics, is one of the greatest triumphs of modern biology, which makes it plain that definite points or particles (genes) in definite chromosomes co-operate with others to control the development of hereditary characteristics.

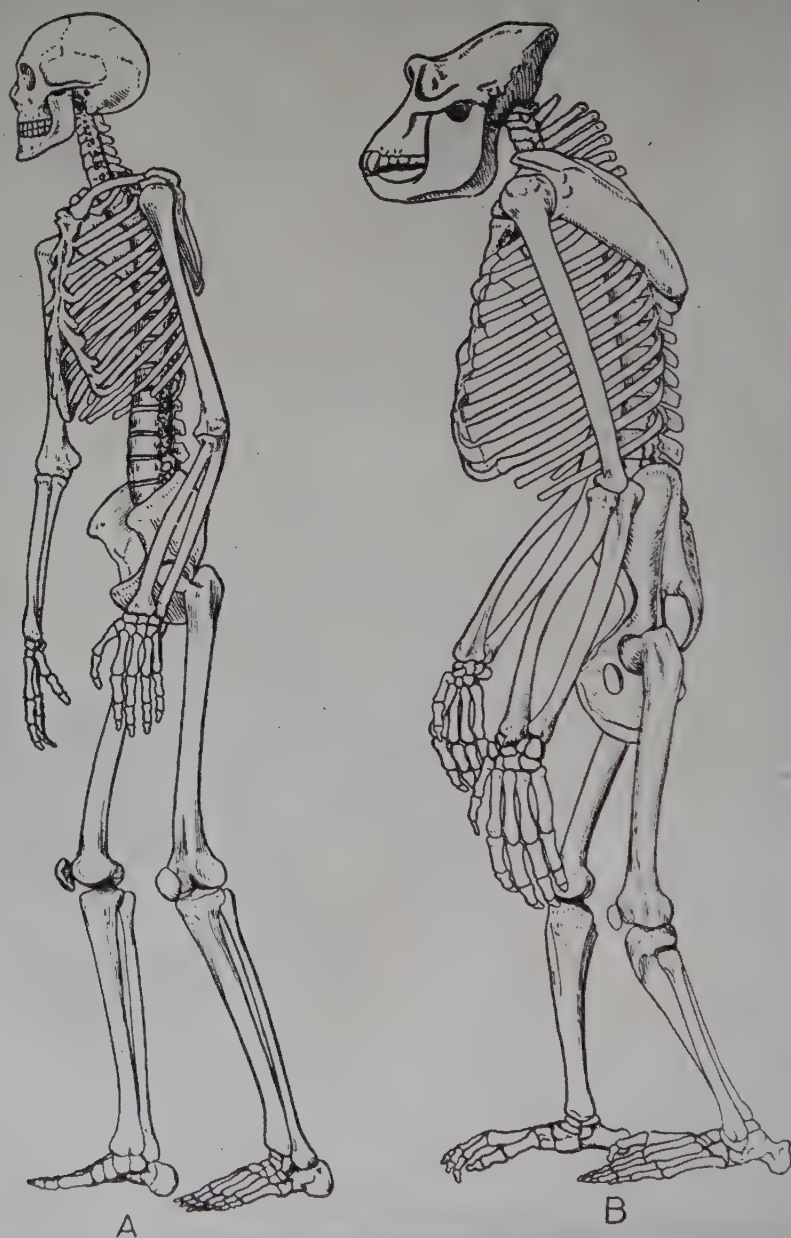
Similar studies of groups of linked mutations corresponding to definite chromosomes have been made in plants, for example in maize, or Indian corn, in which there are ten pairs of chromosomes and ten groups of linked traits (mutations) associated with them.

These mutations are by no means all constructive; many are quite the opposite, distinctly deleterious to growth. They are largely recessives. But it is believed that in chromosomal changes of one sort or another, we have the chief basis of evolutionary progress, which is from within, a matter of germ cells and chromosomes.

But this is only one method of approach toward the mysteries of evolution. Another is the study of geographic races, to learn how a species changes as it slowly or rapidly adapts itself to quite different surroundings, to inquire into the roles of natural selection, isolation, and the direct ac-

tion on growth of the individual, in the development of new species. Although, by general consent at present, "acquired characters" are not inherited, it cannot be gainsaid that individual development in many animals and in more plants is directly controlled and molded by food and water, by atmospheric conditions and temperature.

A striking example of powerful direct action of the surroundings on growth is seen in the extraordinary resemblance to earthworms found among earth-burrowing vertebrates described in this book. In three different groups, amphibians, lizards, and snakes, there are creatures so like earthworms in superficial appearance that it requires careful, expert examination to tell them apart. We leave this case for the readers' investigation, as one of the many unsolved marvels and mysteries of the animal world.



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Skeletons of man and gorilla. A comparison of these shows that man's place in Nature is suggested in his bony framework

SECTION V

MAN AND HIS WORKS

INTRODUCTION

In America the term anthropology is used to cover all studies of the non-historical peoples. What is usually meant is that historical research begins when writing has so far advanced as to leave recorded events and dates, whereas anthropology seeks data of the same import by other methods. An illustration from geology may help. Geology is, in the main, a history of the earth, but there are neither writings nor documents to read. Yet time sequences and relative duration are discovered by geological methods of observing and measuring the layers of materials which constitute the earth. So anthropology observes the different communities of

men with which the historians can do nothing, seeks in the earth for evidences of their past, and the interpretation of this data has evolved into a science. The study of living non-historical peoples is designated as ethnology and the search for evidence of man's past is called archaeology. The more primitive living peoples are suspected of being survivals of the past; further, knowledge of their habits helps the archaeologist to interpret what he may find. So we feel justified in treating anthropology as a science distinct from history, since the methods of anthropology are generally similar to those of geology, paleontology, comparative anatomy, etc.

CHAPTER 25

HUMAN PALEONTOLOGY

THE mystery of man's past has always been a subject of great interest. With the development of science in the eighteenth century came attempts to apply scientific methods to the problem. The rapid exploration of the world by western European nations following the lead of Columbus, revealed several new kinds of people, thus stimulating attempts to classify them and then to explain their origins. From the first, the different tribes of men—savage, semicivilized, and civilized, were seen to fall into

three main classes to which the following names were given, Mongoloid (yellow races), Negroid (brown races), and Caucasoid (white races). Since people of these three classes readily mix, one with the other, they grade into each other, making it difficult to decide how some tribes are to be classed. The question of origin is still far from answered, but each decade gives new information, thus bringing us nearer to a tentative answer.

If logic is brought to bear upon the question, several possibilities are sug-

gested. For one, there might have been three original human types of independent origin. Thus in remote times three separate and quite different types, as Mongoloid, Negroid, and Caucasoid, may have evolved from widely divergent apelike ancestors. Later the descendents of these three types began to mix and scatter over the earth in great variety.

In contrast, another possibility is that there was but one human type originating in a single place, where all men looked very much alike. In course of time, new tribes formed, moved into far countries, losing contact with their ancestors, and thence by mere variation came to be different.

Most people prefer to think of a single origin, like the latter, but final satisfactory proof for either has not been realized to date. Yet, more progress in the scientific study of man has been made in the last one hundred years than ever before.

For a long time the sciences dealing with fossils, geology and paleontology, have known that many forms of life preceded those in existence today. As fossils are more systematically classified the processes of evolution begin to reveal themselves. In the case of the horse, as we have seen, it can be shown how a small creature of many toes became at last the much larger horse we know today, one which walks upon a hoof, or modified toe. All these successive forms of horses became extinct. Man's nearest living relatives seem to be the gorilla, chimpanzee, and the like, so the natural question is, were there intermediate forms which became extinct, leaving, as in the case of the horse, a single surviving type, or, at most, two or three types of man?

A century or more ago it was suggested that the answer might be found if fossil men were ever discovered. Such fossils are now known and new examples are coming to light every year. So our first task will be to review what is known about these human fossils. Incidentally, there are fossil apes and monkeys which complicate the problem, especially because all known forms tend to grade into each other.

HUMAN FOSSILS

The first fossils were found in 1857 in a cave near a place called Neanderthal, not far from Düsseldorf, Germany. For some time no one knew what to think of these fossils. One thing was clear, they were enough like living man to be human. Some of the best scientific men thought they were the skeletons of deformed people, but in time other similar skeletons were found, suggesting that here, after all, was something revolutionary, an extinct type of man, known only by his fossil bones.

Next year came another surprise when a cave called Cro-Magnon yielded several skeletons of a type of man nearer the modern type, but apparently arriving on the scene at about the time the Neanderthal type became extinct.

For about thirty years this was the sum total of information about fossil man, then in 1892 the intellectual world was startled by what was called the missing link, parts of a skeleton found in Java, thought to be an ape man and named *Pithecanthropus erectus*. Opinion was about equally divided between regarding the creature as a super ape or an inferior human being.

In 1911 parts of a skeleton were found in England, in Piltdown, designated as *Eoanthropus dawsoni*. From the first this was considered human.

Passing over a number of finds whose significance is still controversial, we have the discovery of a cave near Pekin, in 1927. This cave yielded the Pekin man, or *Sinanthropus pekinensis*. All of these species of fossil man are now well established, with the single exception of the Piltdown fossil for a number of repeated finds have justified the species designations. Neanderthal, for example, is now represented by more than fifty skeletons, most of them fragmentary, ranging geographically from France to middle Asia. The bones of Java man represent four individuals and Pekin man more than forty.

One way of grading fossil human types is according to their average skull capacity in cubic centimeters. Since in a living man the brain fills the skull, the cubic capacity of a skull is an indication of brain size, or mass. Some of these skull capacities are given in the accompanying table.

TABLE OF SKULL CAPACITIES

	cc.
Cro-Magnon	1,500
Modern man	1,450
Neanderthal	1,420
Piltdown	1,300
Rhodesian	1,280
Sinanthropus	1,000
Pithecanthropus	940
Gorilla	520
Chimpanzee	400

Among living races the Australian brain capacity averages about 1,280, that of white Europeans about 1,450. Thus of the fossil types of man three exceed the Australian native and one exceeds the white man. There is no good proof that small increases in

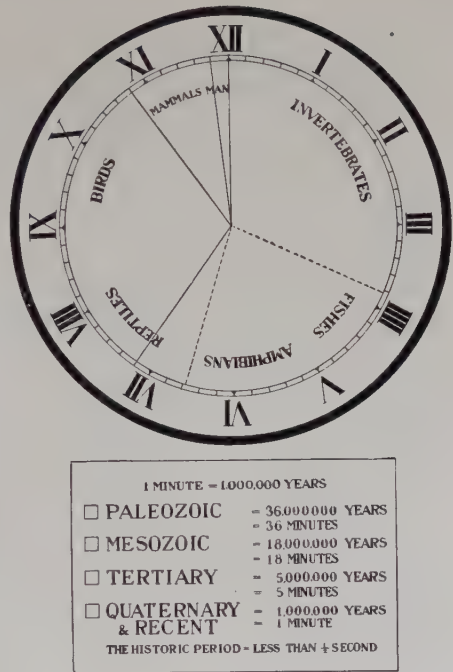


Fig. 1. Diagram in terms of a clock face, showing the relatively recent origin of man

brain capacity mean increased intellectual ability, but large differences between species seem to have such a significance. What is suggested is a wide difference in brain capacity between fossil men and the gorilla; further, the tendency is for fossil men to have a lower capacity than modern men.

DATING THESE FOSSILS

Paleontologists have succeeded in sequencing many fossils. What they mean is that they find them at different depths in sedimentary earth and rock, and since the oldest will be at the bottom and the latest at the top, they can be arranged in a time order, or relatively dated, as it were. However, this method is not so efficient with man, for he appeared upon the

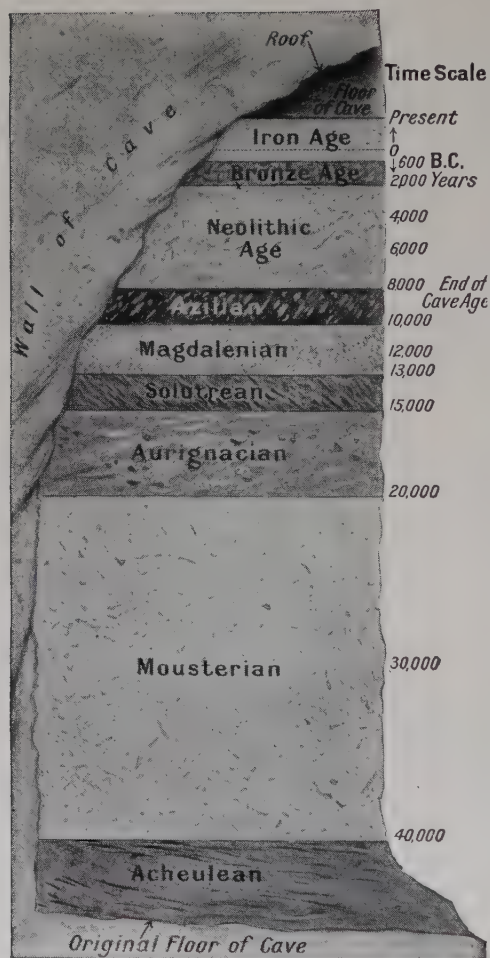


Fig. 2. Sequence of layers in the cave debris of the culture ages in western Europe. The figure is not quite complete since at the bottom should be placed two additional culture layers, Chellean, preceded by Pre-Chellean. The last two stages are known chiefly in river terraces

earth in recent time. This is forcibly illustrated by the diagrammatic use of a clock face, Fig. 1. If we assume that twelve hours represents the time since life forms first appeared upon the earth, then man comes in barely more than one minute before noon.

As compared with many other fossils, such as fish or reptile, all fossil men are nearly contemporary.

So for these human fossils we need another method, one that will discover smaller divisions of time than paleontologists now recognize. It so happens that man himself has left behind accumulations of sediment, debris, or trash heaps, which enable the archaeologist to relatively date him and his evolution in the ways of living. When the increasing cold of glaciated Europe came down upon man in the Stone Age he sought shelter in entrances to caves. An adequate shelter of this kind stood good chance of being occupied for centuries. Bones, ashes, tools, ornaments, etc., when discarded, would be thrown out to form a dump heap. Some of this refuse would accumulate on the floors of these caves, forming layers one above the other. Whenever a new style of ornament or tool was invented, examples of the invention would find their way into the rising dump heap. For some reason the cave dwellers occasionally buried their dead in the floor and out in the dump heap. The position of these objects, just as of fossils in rocks, would reveal their sequences in time and thus relatively date them. The skeletons will indicate the types of men living at the time, and the tools, ornaments, etc., would indicate changes in the ways of living.

An unusual and unique example of the association of man and the cultural objects of his creation is provided in Pompeii, Italy, where a whole city was covered over and sealed by the eruption of the great

volcano, Vesuvius. Clear cut associations of this sort, of course, do not usually occur.

The debris in and around many entrances to caves in France is surprisingly deep and so reveals many changes in ways of living. As one passes from one cave to another, such of these same layers as are present, appear in the same order. This gives a scientific result, one that we can feel sure about, and should satisfy us that the archaeological method of dating prehistoric remains of man is a real scientific procedure.

Fig 2 on page 684 shows an idealized section of a cave with layers present and in sequence beginning with the Acheulean period of the Old Stone Age and advancing to the last Old Stone Age period, the Azilian. This is followed by the Neolithic, the Bronze Age, and the Iron Age. The assumed dates for these periods are given in Fig. 3. These dates are estimates based upon the relative thicknesses of the several layers and so are not strictly accurate. On the other hand, the sequence of the layers is capable of scientific proof.

What we see in Fig. 3 is that the so-called Mousterian Period was a long one. This happens to have been when Neanderthal man occupied Europe. Yet there is another way to

test this sequence. It is not probable that all ancient men lived in caves all the time. Everyone now knows that rivers produce wide, deep valleys and that the sides of these valleys are terraced (Fig. 4). In this case it is clear that the top or highest terrace of the river was where the river first flowed, the second terrace came next, etc. In 1847, a French tax collector, Boucher de Perthes, published a book showing that stone objects made by man were found in all of the terraces in the valley of the

Somme. A subsequent study of these terraces gave a sequence which agrees with that worked out for caves.

This should convince even the most critical that man's ways of living were evolved by slow and tedious steps. His habit of using stone tools is fortunate for us because from them comes most of our knowledge about early man. For convenience and future reference, we present a table of the Old Stone Age periods and some of their characteristics.

When a find of fossil human bones is made, it is sent to an experienced scientist for study. Such a person is familiar with the known fossil human bones and with skeletons of the various races, so that a brief examination, if the bones happen to be of the face or head, will

YEARS	AGES
2,000	AZILIAN
3,000	MAGDALENIAN
2,000	SOLUTREAN
5,000	AURIGNACIAN
20,000	MOUSTERIAN
40,000	ACHEULEAN
100,000	CHELLEAN

Fig. 3. Diagram of the relative length of the various ages based on the relative thickness of the layers

EARLY STONE AGE CULTURES OF WESTERN EUROPE
UPPER AND LOWER PALEOLITHIC SEQUENCES

	Climate	Flora	Game
Azilian	Warm Humid	Deciduous forests	Reindeer, bison, ox- Arctic fauna appear- ing
Magdalenian	Arctic Rising temperature	Steppe and Alpine flora	Same as above
Solutrean	Sub-Arctic Dry	Tundra flora	Same as above Stag, hare
Aurignacian	Cold Dry	Steppe flora	Same as above Musk-ox, asses, wild sheep
Mousterian	Increasing cold, damp	Tundra flora, pine, yew, birch	Same as above
Acheulean	Temperate to cold and dry	Temperate forests Steppe flora	Deer, boar, horse, ox, beaver, otter
Chellean	Warm to torrid	Forest and meadow	Deer, boar, horse, ox
Pre-Chellean	Inter-glacial. Warm or temperate	Same as above	Horse, ox, bison, deer

suggest to him the type to which they belong, which suggestion is then checked by comparing the new bones with the known types. If they closely resemble one of these types, point by point, they are then

identified as another example of that species. On the other hand if they resemble none of these, they can be described as a new species. Long, exhaustive descriptions of each fossil type will be found in the scientific literature, but we have space here to review but the chief characters.

In many cases only parts of the head or face are found. Attempts are then made to restore the missing parts by modeling them in sculptor's clay. There is more or less error in this, but in cases where other examples of the species are found, more often than not, these restorations proved reasonably accurate.

In some cases sculptors have taken the complete skull and modeled over the same

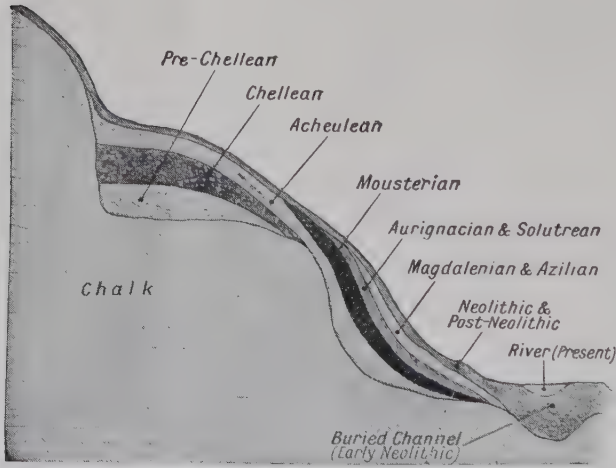


Fig. 4. Diagram of a river valley in France showing the succession of culture ages in the terraces left behind as the river eroded out its valley. (After Boucher de Perthos)

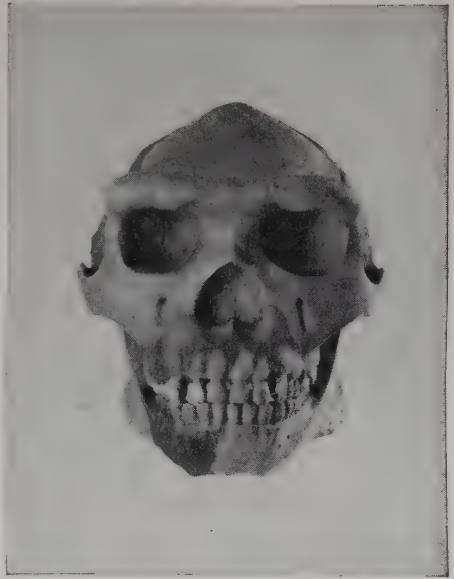
to suggest how the individual may have appeared in the flesh. There is still greater chance for error in such restorations, but again they deserve consideration.

PITHECANTHROPUS ERECTUS

The original find was chiefly the cap of the skull with the eye ridges and forehead. In 1939, the rear, base, and ear region of a skull and parts of an upper and lower jaw were found, all apparently belonging to the same individual. Incidentally there was a cleft in the skull, suggesting that death was due to a violent blow of some implement, possibly a stone tool. Since man is the only creature using tools and since *Pithecanthropus erectus* is considered the earliest known species of man, it appears that murder is an old, old habit.

The apelike character of *Pithecanthropus* is clearly shown in Fig. 5. This restoration agrees well with one made long before by McGregor, who had nothing more to base it on than the original skull cap found in 1891. As in the gorilla, the forehead of *Pithecanthropus* is low, leaving the eye ridges prominent, but the brain case is larger and the face more like that of man. Like most fossil men, even the advanced Neanderthal, *Pithecanthropus* is chinless. You can convince yourself of the difference by feeling of the bone in your own chin and comparing with the illustration.

Geologists are now agreed that *Pithecanthropus* lived in the Middle Pleistocene age, the one immediately preceding the one in which we live, variously estimated as three to four hundred million years ago. Naturally this estimate may be either too high or too low, but it was certainly far back into the past, for the fossil ani-



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Fig. 5. Skull of *Pithecanthropus erectus* restored by Dr. Franz Weidenreich

mal bones found with the four known examples of *Pithecanthropus* are typical of the Middle Pleistocene.

The teeth and jaws are the chief indications that *Pithecanthropus* belongs somewhere near the base of the human family tree. The jaws are large and wide, exceeding those of any known species of man or ape. As one would expect, the teeth are also large. On the other hand, the canine teeth are relatively smaller than is the case with the gorilla, and though surpassing in height the other teeth, are in this respect more like human teeth than otherwise.

Java, in 1931, yielded some fossil skulls from the Upper Pleistocene to which the name *Homo soloensis* was given. In all, eleven skulls were found which seem to belong in general with *Pithecanthropus*, but also show resemblances to Neandethal man. Their skull capacities range from eleven

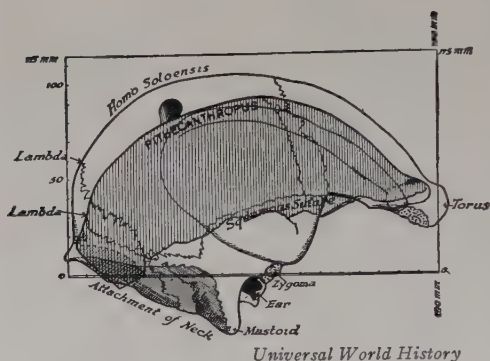


Fig. 6. The differences between Solo Man and his near neighbor Pithecanthropus are well shown in the scale drawing of the two skulls

hundred to somewhat higher figures. Some crude antler and bone implements were found near by. Fig. 7 shows how these skulls were all broken in the same way, as if to make cups or to extract the brains for food or other purposes.

When Dubois proposed the name *erectus*, he assumed the body skeleton of Pithecanthropus was about like that of modern man, who stands erect instead of stooped like the gorilla. No body bones were found with the second Pithecanthropus skull and face bones and there is still some doubt that the thigh bone found by Dubois belonged to the same individual as did the skull cap. Yet there are good reasons for believing that Pithecanthropus did approximate an erect posture. For instance, the skull of man is fitted to his spine in a different manner from that of the gorilla; it so happens that *Sinanthropus*, to be considered next, shows every evidence of an erect posture, and since the resemblance between this species and Pithecanthropus is close, the opinion is that the latter also walked erect.



Carnegie Institution

Fig. 7. Solo Man, lately discovered near the Solo River in Java. Eleven skulls are represented by fragments. The skulls were broken after death, all in the same manner, suggesting that a human being was the agent



Geological Survey of China and Dr. Franz Meidenreich

Fig. 8. From left to right these are the skulls of a female gorilla, female *Sinanthropus pekinensis*, and modern man of the North Chinese type. All are one-third natural size

It is possible that *Pithecanthropus* and his mates—his parents, cousins and children—were alive in Java when the Pliocene deposits of East Anglia were approaching completion. On one scale of reckoning that would be somewhere between 200,000 and 300,000 years ago.

PEKIN MAN

In 1927, Davidson Black observed some manlike teeth from a cave near Peking, but with marked apelike peculiarities. So he assumed a new type of fossil man, designated as *Sinanthropus pekinensis*. Further excavation at the site has yielded fragmentary remains of more than forty individuals. Most of these consist of skull fragments and teeth. This wealth of fragments reveals not merely the type, or species, but the range of individual variation. Again there are individuals of varying ages of both sexes. To enumerate, there are five brain cases, parts of faces from six persons, parts of three upper jaws, fourteen lower jaws, and one hundred and fifty teeth, some of which are

deciduous. From these it was not difficult to reconstruct a reasonable resemblance to the type (Fig. 8).

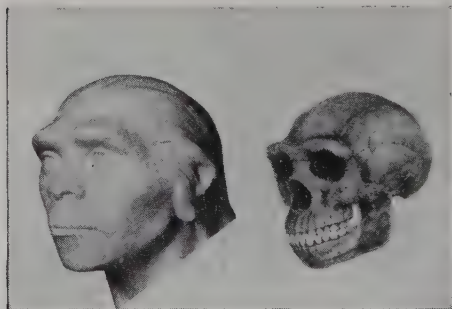
At once we see that *Sinanthropus* was chinless, jaws and teeth larger than those of man, eye ridges heavy, and forehead low. The eye sockets seem larger than those either in man or in the gorilla.

A reconstruction in the flesh has been made (Fig. 9) by Mrs. Lucile Swan, which may be compared with the reconstruction of *Pithecanthropus* by McGregor. The skull of a woman was used in the reconstruction of *Sinanthropus*, so the assumed difference in sex should be born in mind.

If we compare Neanderthal, *Sinanthropus*, and *Pithecanthropus* with modern man, with regard to skull and face form, they form a descending series as above, Neanderthal next to modern man, and *Pithecanthropus* the most primitive. Living man shows a large degree of variation as we proceed from nation to nation, tribe to tribe, and locality to locality. Yet these variations are considered secondary, or as not rising to a level

of importance justifying the pronouncement of two or more species of living man. We consider black, white, etc., as of one species, *Homo sapiens*. Even the small number of individuals, known to us as *Sinanthropus*, show wide skeleton variation which suggests that this type of man varied as much as, or even more than, modern man.

Man is distinguished from the gorilla by his erect posture. For *Sinan-*



Natural History Magazine

Fig. 9. Skull of a Pekin woman and a restoration made by Dr. Franz Meidenreich with the assistance of Lucile Swan

thropus there are enough fragments of skeletons to show evidences of erect posture. We have seen that even *Pithecanthropus erectus* was erect, as the name indicates, but whether less erect than *Sinanthropus* cannot be determined until more skeleton materials from the latter are discovered.

With both *Pithecanthropus* and *Sinanthropus*, skulls without accompanying skeletons are the rule, and these skulls have been broken in ways to suggest violence. What this signifies is a matter of conjecture. Possibly the head was carried home to be eaten or treasured as a trophy. Here one guess is as good as another. Both types of man seem to have used stone tools. *Sinanthropus* used fire, but we

cannot be certain about *Pithecanthropus*. In any case, the use of stone tools would characterize them as human.

So much for the facts. It is now possible to consider what light these fossils throw upon the origin and evolution of man. We have become accustomed to the idea that modern man came up directly from a long, single ancestral line whereas we must now assume an unknown number of fossil human species of which the modern forms of man are the last survivors. How many more extinct fossil types will be found no one can predict. That the early types of fossil man were not confined to a single cradleland is suggested when we note that Piltdown man was in England, *Sinanthropus* in China, and *Pithecanthropus* in Java, while Neanderthal man ranged from western Europe to central Asia. Probably some of these fossil types would intermarry, producing new types, or mutations would occur in separate localities.

Formerly the tendency was to assume the development of man's brain to be the primary stimulus to the use of tools, and so on to civilization, and that erect stature followed, giving the necessary freedom to the hands so that the brain might function. Now we note that erect stature appears long before the human-sized brain we are familiar with, or to put the case in another way, man descended from the trees while he was still more of an ape than otherwise. He could stand erect and use tools, but his brain was still small. Perhaps what followed was that the hands were thus freed for lifting and carrying materials, moving them about, striking them together, etc. This could have stimulated the brain and so led

to evolution in that direction. We do not know when speech began but when it did, the reaction upon the brain must have been direct.

Since fire and tools fashioned from stones are regarded as inventions and handed on from one generation to the next and passed out to neighboring communities, largely by the mechanism of language, we consider it probable that *Pithecanthropus* could talk enough to perpetuate what primitive culture he possessed. Whether *Sinanthropus* could kindle new fire if his own died out, we do not know; perhaps he was obliged to borrow or steal of his neighbor, or wait until a thunderstorm started a fire near by. There is every reason to believe that man knew how to control fire and keep it alive, long before he knew how to make it by wood friction or percussion.

PILTDOWN MAN

Eoanthropus dawsoni, or Piltdown man, is still a puzzle. Jawbone fragments of two individuals have been

found but only parts of one skull cap. Many specialists refuse to believe that the fragmentary skull cap belongs to the same individual as the jaw bone because the skull cap calls for a large brain, whereas the jaw was chinless and otherwise primitive. So the curious thing about this type of fossil man is that the lower jaw is very primitive whereas the forehead is high and almost modern. Then too, the brain capacity is estimated at about 1300 cc., relatively high for fossil man. Thus we find in combination with some of the most advanced human characters others very primitive. This unusual association causes many qualified experts to regard the skull cap as belonging to a form of modern man and the jaw to fossil man.

Another difficulty has been to agree on the geological age of this type. The tendency was to place it in early Pleistocene which would make it older than *Pithecanthropus*. It may well be, for all we know, though that seems inconsistent. Fig. 10



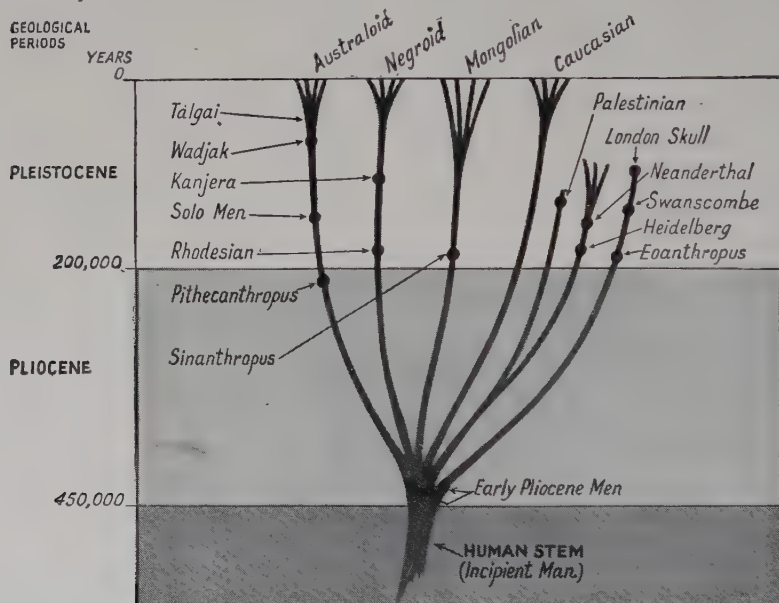
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Fig. 10. Comparison of the skulls of prehistoric human types. Left to right, *Pithecanthropus erectus*, Piltdown Man, Neanderthal Man, Cro-Magnon Man. Restorations by J. H. McGregor

shows all the main fossil faces except *Sinanthropus*. The assumption here is that geologically Piltdown man falls between *Pithecanthropus* and Neanderthal. It needs no anthropologist to see how out of place he looks in that position.

In 1935, a skull fragment was found in the valley of the Thames, near

Reid Moir first announced crude stone implements from East Anglica which are early Pleistocene if not actually back in the Pliocene. The tendency is to rate Piltdown man as of about the same geological age. The other possibility is that the Swanscombe skull is much older than Neanderthal skulls, or than any other equally advanced



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Fig. 11. A diagrammatic family tree for man, showing probable evolutionary lines

Swanscombe, in geological formations which dates it as earlier than any European Neanderthal skull known. It suggests the Piltdown skull cap. Found ten years before, a skull fragment from a deep pit in the city of London also suggests the Piltdown type of skull. This seems to suggest that a human type with brain case even more advanced than Neanderthal, lived in England very early, and may have survived for a long time.

One important point to keep in mind is that the oldest stone implements seem to be found in England.

form. At this point speculation takes the place of knowledge, but the chances favor this skull as the earliest advanced form of man, the first tool-maker in western Europe.

THE ANCESTORS OF MODERN MAN

The problem of first importance in the science of man is to identify the immediate ancestors of modern man. Obviously the chinless *Pithecanthropus*, with his low forehead and ape-like eyebrows, is a long way down the line. Sir Arthur Keith and others have attempted to place all the known

types of man upon a family tree, although many doubtful assumptions are made in the creation of such a tree (Figs. 11 and 12).

A skull was found (1921) in a mine at Broken Hill, Rhodesia, South Africa, now designated as Rhodesian man, or *Homo rhodesiensis*. As a type, he ranks lower than Neanderthal and shows some similarity to the Australian black. His brain capacity was about 1280 cc., so he stands between *Sinanthropus* and Piltdown. In 1932, L. S. B. Leakey found two fossil skulls at Kanjera, Kenya, East Africa, which are considered examples of a primitive Negro type. So the tendency is to consider Rhodesian man and later Kanjera man as two successive points in the early Negro line of ascent.

The Australian continent has yielded some fossil skulls, as Talgai man and the Cohuna skull. These are considered ancestral to the modern Australian native. Possibly *Pithecanthropus* is a still more remote ancestor.

Now we turn to Asia, the assumed original home of the Mongoloid stem. Near the Pekin man site are some caves once inhabited by a Stone Age people comparable to the Upper Paleolithic cave dwellers of western Europe. The study of a few skulls found in these caves vaguely suggests modern Chinese. Furthermore, there are certain basic resemblances between Pekin man and these same Chinese, hence the tendency is to regard the evolution of the modern Mongoloids (Chinese, Japanese, Malays, and American Indians) as descended from *Sinanthropus*, and possibly in turn from *Pithecanthropus*.

Finally, what of the ancestors of the Caucasians? The Neanderthal became extinct in Western Europe, or was

displaced by the Cro-Magnon. In England, Piltdown, Swanscombe, and then the London skull seem to represent another line that vanished. Perhaps new finds of fossil men will clear up this puzzle too.

We can now return to the question of a single origin for these three main stems of mankind, the Negroid, Mongoloid, and the Caucasoid. The obvious fact that several kinds of men evolved and ultimately became extinct, as *Pithecanthropus*, *Sinanthropus*, Neanderthal, etc., increases the probability that the Negroid, Caucasoid and Mongoloid types were also formed during this early period and were the sole survivors. However, this is nearly as much of a guess as the single origin theory.

SOME FOSSIL APES

So far we have reliable evidence of a human fauna in Upper Pleistocene time, the similarity of which to the gorilla and other apes cannot be denied. On the other hand, in erect posture, dentition, and size of brain, all of these human types approach living man. Also they seem to be able to make crude tools and to use fire. This gradation from apelike men to modern man suggests that there were also menlike apes to bridge the gaps between living apes and the extinct *Pithecanthropus*, *Sinanthropus*, and *Homo rhodesiensis*.

A few such fossil great apes have come to light. It is generally agreed that a Pliocene fossil named *Dryopithecus* represents the remote ancestral horizon from which ultimately resulted the living apes and man. *Dryopithecus* would then be the more immediate ancestor of the fossil apes.

The first important find of a fossil great ape was *Australopithecus afri-*

canus, found near Taungs, Bechuana-land, South Africa, 1924. This is frequently spoken of as the Taungs skull. The specimen proved to be the skull of a young ape with its milk teeth. But in 1936 the incomplete skull of an adult was found, which, if not of the same species, is of the same genus, *Australopithecus*. The geological horizon has been determined as Upper Pleistocene and so might be a contemporary of *Sinanthropus*, which is to say that types of fossil manlike apes were roaming about when the apelike men were building fires and making crude stone tools.

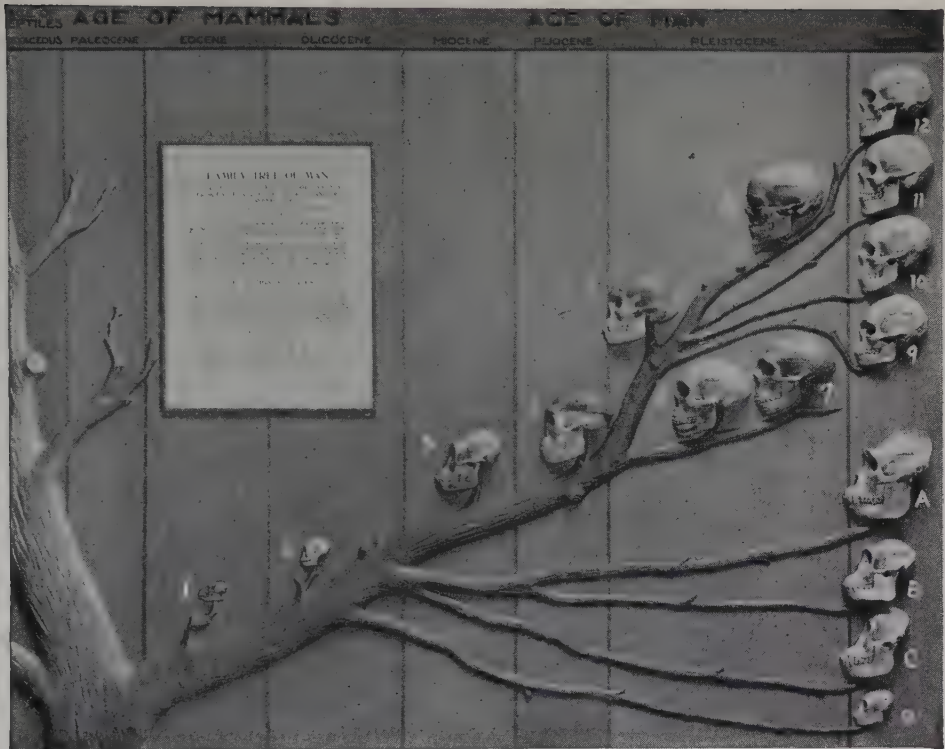
Future discoveries may be expected to produce additional fossil manlike apes to more completely fill the gaps in the series. There is little reason to suppose that all the types produced by nature are known. We have evidence of many forms of fossil men and so there should have been many examples of manlike apes. Why all these forms should have become extinct, to leave the lone species *Homo*, or modern man, no one can answer satisfactorily.

MOUSTERIAN NEANDERTHAL MAN *HOMO NEANDERTHALENSIS*

We know a great deal about the Neanderthal man. In the first place more than a hundred individuals are represented in our bone collections. He has left behind thousands of stone implements in deep deposits of debris, and it is not far wrong to say that he laid the foundation of civilization. One of the most complete skeletons of this type was found in a cave near the Chappel-aux-Saints, Dordogne county, in France, which is regarded by many as the type specimen for western Europe. The skull was used by Professor McGregor to make a

bust showing his concept of what the owner of the skeleton looked like when alive. As stated at the outset he was chinless, though less markedly so than *Sinanthropus*. His jaws and face were large, his nose broad, his eye ridges heavy, and his forehead sloping backward. His head was relatively large, his brain capacity ranged from 1,300 to 1,600 cc. and averaged about 1,420 cc. His stature, as estimated from his bones, ranges from five feet one inch to five feet five and one fifth inches. In habitat, he ranged as far east as central Asia and, as may be expected, comprised several varieties. Some of the most important finds are:

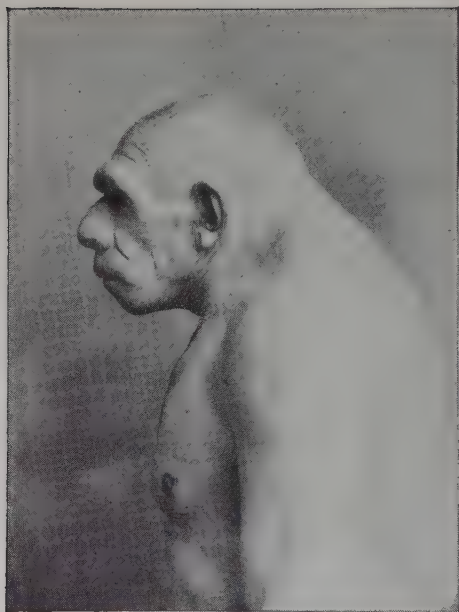
1. The Gibraltar skull found in 1848.
2. The original Neanderthal skulls found in 1856, near Düsseldorf, Germany.
3. The Spy skulls from a cave near Dinant, Belgium, in 1887.
4. The Krapina skull from a cave near Krapina, Croatia, in 1899. There were about a hundred fragments of human bones in this cave, somewhat at variance with the Neanderthal type in France, but still of the same general type.
5. The Chappel-aux-Saints skull in a cave in the Dordogne county, France.
6. Skulls from the Cave of the Robbers, near the Sea of Galilee, Palestine, in 1925.
7. A skull from the Judean hills, near Jerusalem, in 1928.
8. A skeleton from the Cave of the Oven, on the west side of Mount Carmel, in 1932. All the Palestine skulls are clearly Neanderthal, but represent a more primitive



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Fig. 12. Key to stages in the family tree of man

1. Primitive primate (*Notharctus osborni*). Fossil skull and jaw, slightly restored, of Eocene age, Wyoming
2. Prototypal anthropoid. Reconstruction based on fossil jaw (*Propliopithecus haeckeli*) of Oligocene age, Egypt
3. Primitive anthropoid. Reconstruction, based on fossil jaws (*Dryopithecus*) of Miocene age
4. Trinil Man. Reconstruction, based on fossil skull-top (*Pithecanthropus erectus*) of Pleistocene age, Java
5. Piltdown Man. Reconstruction, based on fossil skull and lower jaw (*Eoanthropus dawsoni*) of Pleistocene age, England
6. Heidelberg Man. Reconstruction, based on fossil jaw (*Homo heidelbergensis*) of Pleistocene age, Germany
7. Neanderthal Man. Fossil skull and jaw (*Homo neanderthalensis*) slightly restored, of the Old Stone age, Europe
8. Cro-Magnon Man. Fossil skull and jaw, slightly restored, of late Palaeolithic age, France
9. Australian Black-fellow. One of the most primitive of existing human races
10. Hottentot. Representing the Negro group of races
11. Chinese. Representing the Mongolian group
12. American. Representing the Caucasian group
- A. Gorilla, Africa
- B. Chimpanzee, Africa
- C. Orang-utan, Borneo
- D. Gibbon, India



Field Museum of Natural History

Fig. 13. A restoration of Neanderthal Man. No attempt was made to restore the hair of the head and body

form than those found in western Europe.

9. Finally, in 1930, in the Cave of the Kids, Mount Carmel, more than ten individuals were found, probably of a more advanced type. The associated stone tools remind one of the European Neanderthals, but they have rudimentary chins and rather large brain capacity. They may be an intermediate type between Neanderthal and modern man.

Once before we mentioned the sequence of culture periods of western Europe. Whether these will hold for Asia and Africa remains to be seen, but the indications are that at least the earlier horizons will correspond fairly well. The European periods are considered as constituting the Paleo-

lithic, or Old Stone Age. For the names and order of these periods see Fig. 2 and note in Fig. 3 that the Mousterian period lasted a long time. It begins in the retreat of the third ice age and continues into the peak of the fourth ice age, to be followed by the Aurignacian, Solutrean, and the Magdalenian. The last is a recurrent cold period, or sub-glacial period. The Neanderthals were the folk of the Mousterian period, which is regarded as divided into three parts.

Changes of climate in western Europe were accompanied by radical changes in the vegetable and animal life. According to geologists there have been four great ice ages in the northern hemisphere. Between these ice ages were periods of warmer—though fluctuating—climates. The amounts of rainfall varied from arid to humid, somewhat out of step with the changes from cold to warm. Neanderthal man appears in Mousterian time which lies between the third and the fourth ice ages, extending almost to the middle of the latter. It is customary to divide the long Mousterian period of the Old Stone Age into three parts, early, middle, and late, or first, second, and third.

Each of these parts of Mousterian time shaded into the others, with a progression of changing climates.

1. Early Mousterian time is characterized by a warm to cold, arid climate. The game animals were chiefly rhinoceroses, elephants, bison, horses, cattle, reindeer, etc. The reindeer seem to have dominated, so Mousterian time is sometimes called the reindeer period. The cold increased throughout, as did the humidity.

2. Middle Mousterian had a cold, moist climate. During this period

many of the large animals are leaving central Europe because Arctic weather is spreading southward. Reindeer continue abundant, the cave bear is in evidence, and horses, cattle, bison, and the woolly mammoth are still to be met with.

3. The last Mousterian sub-period culminated in an extremely cold climate as the peak of the fourth ice age approached. Most of the large game animals survived and among other northern arctic creatures was the musk ox. The plant cover was reduced to what one may now see upon the arctic tundra, open meadows frozen solid during the long frigid winters.

There were men in Europe before Mousterian time. Three rather long Stone Age periods have been determined as the Pre-Chellean, Chellean, and Acheulean, but Neanderthal man first appears in the Mousterian. There is evidence to show that these Stone Age periods shade into each other as types of man come and go, each learning new ways of living from the others. We should fix it in our minds that the Stone Ages are periods in more advanced equipments for living, that they have been ascertained by a study of the differences between the levels of artifacts and camp debris, as one examines the deposits in caves and around rock shelters.

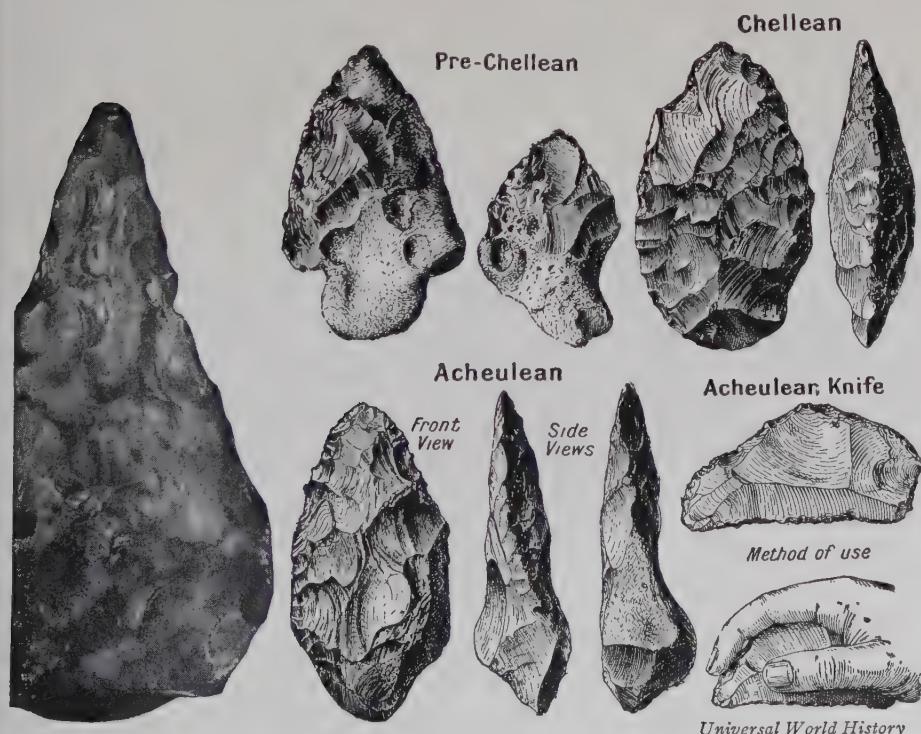


Fig. 14. Early methods of chipping stone. The hand axe on the left is the earliest form of axe. The other implements are made by shaping the original pebble, chipping on all sides. The implement is thus the core of the original pebble

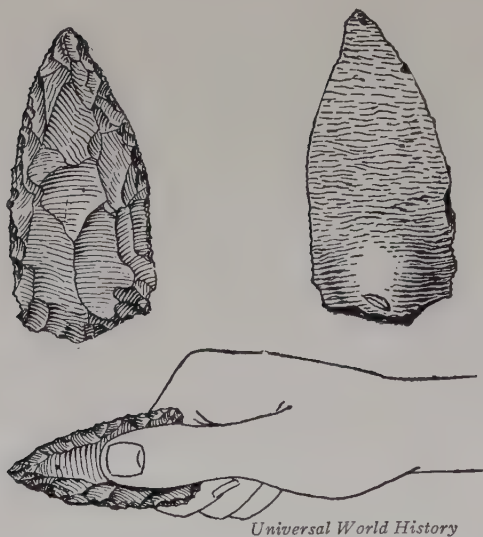


Fig. 15. A Mousterian point and its use. Left top, chipped side of point; right top, unchipped side of original flake

So far as we know the Neanderthals were the first people in the world to invent burial. Had the earlier peoples hit upon this idea we should have found more of their bones. The Neanderthal peoples went further in developing an idea of immortality, else why should they have placed implements and food with the body. Of course, we can not tell just what forms these beliefs took, but since burial has persisted through the ages, associated with similar ideas, we are warranted in assuming that the Neanderthals were no exception. In any event, burials are dated by the imperishable artifacts interred with the dead, for we know the sequences of changes in artifacts, skills, and inventions.

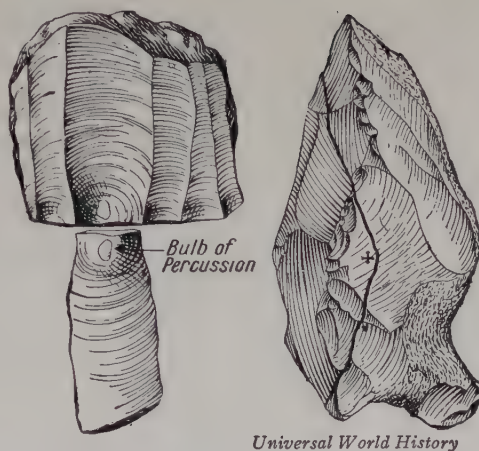
Neanderthal man used fire but apparently some of his predecessors did that too. Like them he used stone tools.

We come now to another contribution he seems to have made. Before

his time stone tools were made by reshaping stones as nature left them. Water rolls stones one upon the other, grinding down their surfaces and rounding their edges. Even modern man selects from these water-worn stones those that make good pounders, a missile to throw at something, to serve as a grinder, an anvil, etc. Again nature crushes rock leaving jagged and often sharp-edged pieces. These can be used for scraping and even for cutting, if the points and edges are not too blunt. All this is to remind one that if man had the right idea he could find rude stone tools ready made for him. Naturally the next step would be to improve upon what nature provided. The stone tools of the three early periods were made by chipping off the edges of a stone rounded by nature. What is left after the chipping process is called the core. Figure 14 shows the progress in toolmaking from the Pre-Chellean to the Acheulean. Almost at the outset man discovered that flints could be shaped easier and faster than most other kinds of stone. So flints became the chief tool material. By striking in the right place on a piece of flint, long, slender flakes will be released. Before Neanderthal time these flakes were disregarded and the heavy cores retained as tools. Neanderthal man, however, began to use the slender flakes, rechipping their edges and ends to fashion pointed knives or spear heads. Figure 15 shows two sides of the flake and the way in which it could be held in the hand for cutting or scraping. Figure 16 illustrates the manner of striking off flakes. This was an improvement over the Acheulean practice because small and

delicate tools could be made with keener edges. Eventually the refinement of the chipping technique would make chipping flint an art, resulting in beautiful symmetrical points. We should remember that Neanderthal man had a large brain and since he made two great innovations, burial (religion) and flake chipping, he cannot be charged with failure to use his surplus brain tissue.

As the climate gradually was growing colder, the mouths of caves were sought. The air here would be warmer than outside, but these men had fire, maintained hearths, and so had heat as well as light. It is probable that skin clothing was invented, but if so, none of it survived. Of one thing we can be certain, these men could not have survived the arctic winters of



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Fig. 16. Mousterian method of working flint. A flake struck from the core (left). Sometimes one side of a pebble will be chipped before the flake is struck off. X indicates the point struck to remove the flake

the third Mousterian sub-period without some kind of foot wear and cloth-



Field Museum of Natural History

Fig. 17. Habitat group in the Field Museum of Natural History showing a camp of the Mousterian Neanderthals

ing. They may have known how to twist sinew into cords for snares and even into thread for sewing skins together, but all this would have rotted away long ago. That wooden handles were made for their tools is unlikely since none of them seemed shaped for the insertion of handles. Like the living Australians he could have shaped long, slender pieces of wood and sharpened their ends to use as spears. He could have worked out wooden clubs with his stone tools and he could have made awls and daggers of wood. The curious fact is, however, that though he had more bone, antler, and ivory than any toolmaker could use, we find no real bone tools. Yet he did use large bones as kinds of chopping blocks.

We have no trouble in proving that these Neanderthals were good hunters. The thousands of broken bones around their caves and rock shelters suffice for that. These bones can be identified as wild horse, cattle, wild hog, bison, reindeer, bear, elephant, etc. How they killed these large animals we do not know, but by using their brains and working together as a team, they could devise ways to do it, such as making traps, driving them over cliffs, etc.

The sad part of this tale is that as the cold became intense and Mousterian time approached its end, the Neanderthal man of western Europe also came to an end, as he did in Asia. Yet he had lived a long time, some of the conservative estimates are thirty to fifty thousand years. The time of his extermination is placed at twenty thousand years ago. In other words, the stretch of time over which he survived is greater than all the time from their extinction to the present!

CRO-MAGNON OR AURIGNACIAN MAN

The Aurignacian period followed the Mousterian. From now on changes in ways of living occur with greater frequency. The usual estimates for the duration of the Aurignacian period are five to six thousand years. Recorded history begins about 3000 B.C., so the time span of the Aurignacian is about the same as that for human history.

The climate was still cold, but the peak of glaciation was passed and the falls of rain and snow were slowly decreasing. By the middle of the Aurignacian the climate was rather dry, and there were heavy dust storms spreading about deep layers of sand and soil as in the present dry-plains area of the United States. However, the regions formerly covered by the tundra became grass-covered plains over which roamed wild horses, cattle, reindeer, and other grazing animals.

The most important event in early Aurignacian time is the appearance of a new type of man. The type station is a cave, near the town of Cro-Magnon in southwestern France. In 1868, five or more skeletons were found here, associated with flint implements and perforated shells indicating necklaces. The skull and a restoration are shown in the illustrations.

The first thing to be noted is that these people have a modern look. They have chins, their foreheads are moderately high, and the eyebrow ridges less prominent than in Neanderthal man. Their faces are broad, but on the whole they might pass unnoticed had they survived to the present. Naturally, we know nothing about the color of their skins, the

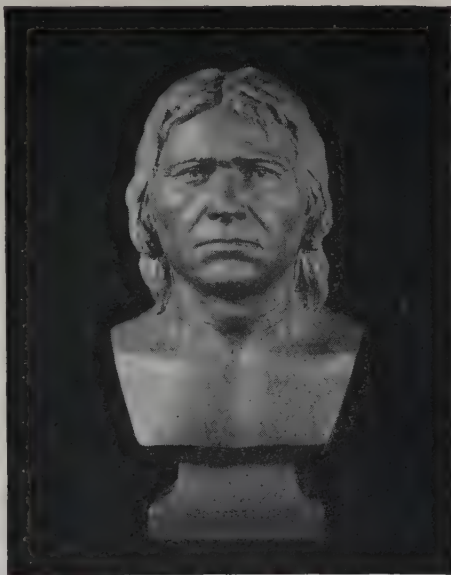
amount of hair on the face and body, etc. They were a tall people. The type male skeleton was estimated as six feet four and one-half inches. The best preserved examples of these skeletons averaged about six feet, which is more than most modern races can claim. The skull capacity is over 1,500 cc., as high or higher than that for modern man. The anatomical characters are not Negroid but rather Mongoloid. Here then we have the first appearance of what may be considered a type of modern man.

These Aurignacians either invented or brought with them into Europe a number of important inventions. Like their predecessors, they used fire, made stone tools from flakes rather than from cores, and buried their dead with artifacts and offerings. In addition, however, we find for the first time, handles for tools, awls, well-shaped dart points, paint tubes, necklaces, carving, etching, and painting. We suspected that the Neanderthals might have attempted to sew skins together by punching holes and then thrusting sinew thread through the holes, but there were no real evidences of this. Now we find awls which could have been used for that purpose. As may be expected, the variety of stone tools is greater than ever before. Among others are chipped flints so small that they could have been used in executing fine engravings.

SOLUTREAN MAN

Following the Aurignacian was a relatively brief period, the Solutrean, the type station of which is in western France—about two thousand years in all.

Two new features appear here. In chipping flints a high level of skill and



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Fig. 18. Restoration of Cro-Magnon Man by Dr. James H. McGregor

beauty was attained. Flakes were now chipped on all sides, like the arrow heads we find in the United States. In some Solutrean artifacts the fineness and beauty of chipping has rarely been equaled. The other notable invention is the needle. Now we have no reason to doubt the practice of sewing.

The skeletons show certain differences from Cro-Magnon in that they are longer headed but are just as modern. For this reason Solutrean man is sometimes considered one of the ancestors of modern European races. They seem to have migrated into France from the east and were contemporary with the Cro-Magnon.

THE MAGDALENIAN

Next in order is the Magdalenian, considered to have run its course in some 3,000 years. The climate of this period seems to run through three

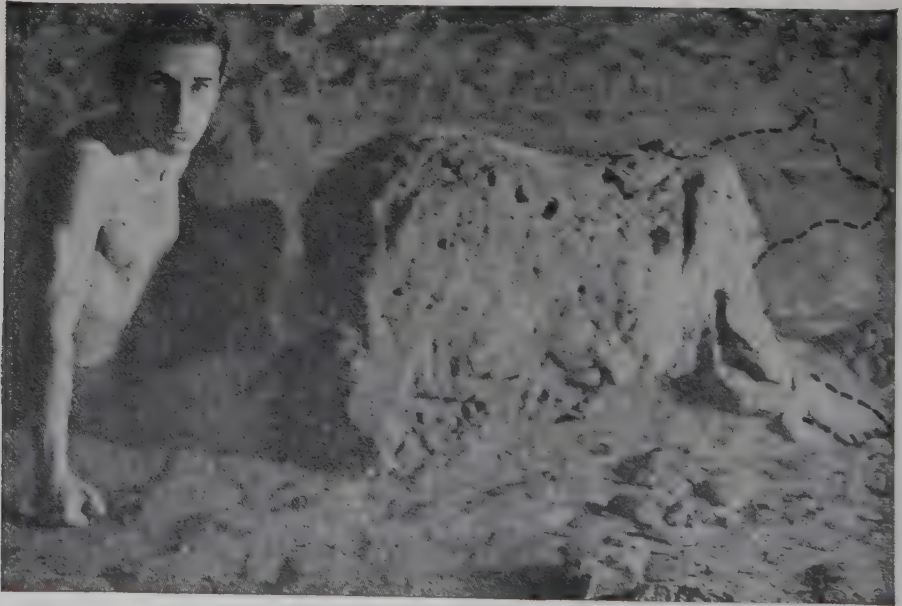
successive cycles. At the outset the arctic cold seems to have returned because the species of animals killed for food suggest tundra life, as the musk ox, woolly mammoth, woolly rhinoceros, and the reindeer. The bison seems to have been abundant. The glaciers again came farther down the Alps, so living conditions must have become harder, intensifying the use of caves and rock shelters.

But with the middle cycle, milder but still cold and dry climates were returning, bringing with them the grass-covered plains, as in the Mousterian. This was but a temporary retreat of the ice.

Then came another advance of the ice, the last of which we have any record, and their were varying fluctuations of climate, with the tempera-

ture, as a whole, falling. So through Mousterian, Solutrean, and Magdalenian time, man was more or less a cave dweller, the cold presenting the chief problem in his effort to survive.

Types of Cro-Magnon man persisted throughout the three periods, though there are suggestions of other types on the margins of Europe and local variations among the Cro-Magnon themselves. In Magdalenian time they introduced some innovations. For the first time bone implements become frequent and quickly attain variety and excellence. It seems odd that with all the bone available early man ignored this convenient and useful material. If you care to form a mental picture of the Magdalenian bone industry, go to a museum where



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Fig. 19. After swimming for nearly a mile, sometimes under water, through a subterranean stream, Norbert Casteret discovered, in the flooded cavern of Montespan, the Magdalenian clay model of a bear, shown here with its finder. Its head, shown dotted, was an actual bear skull which has fallen off, and the body was riddled with spear thrusts

there is a good display of Eskimo objects. The objects will be different in details but otherwise similar. The bone harpoon appears in Magdalenian time in many forms. Another important invention is the spear thrower. Among the novel innovations are drawings showing masked, costumed human figures dancing. Finally, in art appear polychrome painting and composition to which should be added sculpture in clay. Painting in caves would seem to demand lamps; they too, occur (Fig. 20).

THE DECLINE OF THE CAVE PERIOD

After the Magdalenians no more cave paintings were left for us to enthuse over. The survivors of the Magdalenian may have painted upon perishable materials for all we know, but the carvings they left behind do not suggest interest or skill in representative art. No doubt new peoples were crowding into western Europe bringing new ideas. The climate was becoming milder and moist. Forests began to cover the country and the ways of living to change. No longer need the shelters of caves be sought. The country would support an increasing population, and in numbers there was strength and diversity.

THE INVENTION OF ART

That art is an invention may be an astonishing statement to the reader. What we refer to as art are the many technical processes used in the production of works of art. Men of the Old Stone Age evolved line drawing, engraving, carving, modeling in clay, and painting. They had taken the first steps in composition. Their best drawing and modeling will stand comparison with modern standards. The custom of the time was to draw and



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Fig. 20. A model of the Castillo Cave in northern Spain showing the cave paintings

paint upon the stone walls of caves, otherwise examples of their art would not have been preserved. Art work of this character appears with the Aurignacians, the forerunners of modern man, and reaches its highest level in Magdalenian time. Neanderthal man seems not to have ventured into representative art, though he was not entirely ignorant of simple ornamentation. If the objection is made that Neanderthal man drew and painted upon skins, we cannot say that he did not, but neither did he sketch by marking upon stone. Since he lived in caves it would seem strange—assuming he knew anything of art—that he did not try something on the stone walls around him. The contributions of the Neanderthals were in working stone. His achievements in that craft are sufficient to give him his due place in history.



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Fig. 21. Sketch of a trout drawn in sand from the cave of Niaux

It is obvious that art begins with the Aurignacians and we know that smooth sand was used for drawing. For example, in the cave of Niaux an artist used the end of his finger to draw a beautiful miniature bison and a marvelously realistic trout. A thin transparent layer of stalagmite spread over these sketches and fixed them permanently. If of no other significance this explains how these ancient artists acquired their skill (Fig. 21).

Monotone and polychrome art were advanced in Magdalenian time. The steps between drawing, engraving, and

polychrome painting are clear in the many examples upon cave walls. Sometimes the outlines of the animal and some of the essential lines were engraved in the stone, and then the color was added. In other cases line drawing in black

or red was used to define the figure after which the paint was applied. The trick of shading in color to indicate depth was well understood by the time the highest level of Magdalenian painting had been reached.

In one phase of art the Stone Age artists were weak; we refer to composition. However, the famous engraved reindeer (Fig. 22) is usually considered an example of composition, frequently interpreted as a reindeer grazing.

Carving in full relief was well executed, as in Fig. 24, a lifelike por-



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Fig. 22. This drawing from the cave at Font-de-Gaume pictures two reindeer, one kneeling to graze

trayal of a horse's head from the cave of Mas d'Azil, France. Among the most delicate carvings is that of a grouse or a ptarmigan on a bone implement handle, on which the carving detail is as delicate and realistic as modern Alaskan Eskimo carving. Even a few full round statuettes of women are known, the most famous being the Venus of Willendorf done in stone. And while we are speaking of human subjects, notwithstanding the fact that the Stone Age artists of Europe seldom drew or painted their own kind, they have left behind a few examples to show that they could. One intriguing picture is that of a man dancing in the mask and skin of a deer, the pose of which is next to perfect.

Finally these old artists could model in clay, just as modern sculptors do. We know this because two happy accidents have preserved classic examples of their work. The best known are the two bison in Fig. 23. The other example is a clay bear in the cave at Montespan.

Naturally the question arises as to why these artists sought the dark,

secret, inner chambers of caves to execute their masterpieces! We cannot answer but we suspect this to be religious art in part, in that the painting of the picture was a ceremony to enhance the increase of game and success in the hunt. Similar things were done by natives living within the past century, and probably are still done in New Guinea.



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Fig. 24. Superb carving of a horse's head from reindeer antler, found in the cave of Mas d'Azil

The Stone Age men of Africa, generally contemporaries of those in Europe, drew more human beings than otherwise. Their animal figures were in motion, rather than static as in Europe. Composition was highly developed in their hunting and battle scenes. In Spanish caves and again in North Africa, travelers have observed many such paintings, most of which seem to be contemporaneous with Stone Age art in France. The example of the dancing men, taken from the cave of Vallorta, Spain, is sprightly enough to suit the most fastidious. Curiously enough, even in modern times, the tiny Bushmen of South



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Fig. 23. Male and female bison, modeled in clay from the Tuc d'Audoubert



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Fig. 25. An early engraving from the cave of La Loja in Spain

Africa have made lively cave paintings showing men and animals running at top speed.

The significance of this study of art is that it is one of man's earliest achievements and as such precedes many important mechanical and social adjustments. Surviving primitive peoples also manifest interest in art and decorative handwork, so that whereas the early people of the Stone

Age seem to have discovered the techniques of art and to have achieved unexpected skills in their use, living primitive peoples continue to show similar interest and capacity for acquiring the necessary skills. All of which is equivalent to saying that realistic art in all its forms is one of the earliest manifestations of human life and can in no manner be associated only with recorded history.

CHAPTER 26

MODERN PEOPLES

AS men increased in numbers they seem to have become more mobile, spreading over the entire habitable world. Those that survived were so nearly identical biologically that they would crossbreed. No one knows the history of the formative period in which the three main types became stabilized. It is quite possible that each evolved from a different type of extinct man. Which is to say that the ancestors of the Negroid represent an African survival, the Mongoloid, an Asiatic survival and the Caucasoid, a mid-Euro-Asiatic survival. Yet, originally they were so near biologically that even to this day the crossing of a male and female anywhere will result in offspring. The more numerous and mobile a group of people become, the more they would mix back and forth until it would be impossible to discover all the parental varieties that combined to make the people as we find them. Domestic animals give historians similar difficulties, particularly dogs. The cases of man and dog are not quite parallel, for man has executed conscious control over the crossing of dogs, whereas he has not exercised such control over his own kind.

This problem of discovering the origin for the primary differences between the various types of men has from the first stood as a challenge to the genius of man, nor has anyone yet produced a satisfactory scheme of classification for the peoples of the world. The scientific way to approach the problem has been to compare individuals one with another and in that way establish types, as is the

way with plants and animals. In the end this resolves itself into the choice of specific anatomical characters. So it may help our understanding of the problem if we review some of these characters.

THE HAIR

The most distinctive characters are to be found in the hair, particularly head hair. For example, the hair of the Indians of the New World and the Mongoloids of Asia is uniformly straight and black. As a genetic character this hair tends to be dominant; we suppose that is why this type of hair is recurrent over so great a portion of the earth's surface—something more than one half of the land surface. Mixed-blood Indians show a dominance of straight black hair. So the usual custom is to regard straight black hair as the outstanding character of Mongoloid peoples.

Negroid peoples have a kinky or woolly type of hair, also uniformly black. This type of hair is widely distributed, especially in Africa, New Guinea, Australia, etc. It is persistent, tending to dominate in mixtures but possibly to a less degree than straight black hair.

Finally, Caucasoid peoples have wavy or curly hair, usually not black, varying from brown to blond and red. The map (Fig. 1) showing the distribution of Mongoloid, Caucasoid, and Negroid peoples could just as well be a map showing the distribution of these three types of hair before the fifteenth century, since which time there have been mass mi-



Fig. 1. Map showing distribution of the Mongoloid, Caucasian, and Negroid peoples

grations of Negroid, Caucasoid, and Mongoloid peoples, resulting in a different form of distribution. The usual procedure in all discussions of this kind is to refer to the beginning of the fifteenth century.

We have said that in large masses of the population these types of hair are uniform and that straight black hair tends to persist in blood mixtures, but there is a great deal of variation on the margins of the large areas designated on the map. Here and there are small clusters of people, like the Ainu in Japan, who differ from those around them and who maintain their individuality.

Attempts have been made to classify head hair by measurement and microscopic examination. At one time it was believed that all Negroid hair was kidney shaped in cross section, Mongoloid hair circular, and European hair oval, but later it was observed that the hair of a single individual varied greatly from one part of the head to the other. In a general way the distinction holds, but is not constant enough to be taken as a positive means of identification. Some investigators claim that the shape of the scales on the outside of the hair shaft is an index of classification but this has not been worked out.

Color of the hair shows some variations too, especially among Europeans and in marginal areas where people of different hair color are neighbors, giving opportunity for intermarriage and the resultant mingling of types.

SKIN COLOR

The distinctions between Negroid, Mongoloid, and Caucasoid are fairly definite in respect to skin color. Even here there are differences in shades that may be confusing. For example, Caucasoids range from the white of the blond Scandinavians to the dark browns of the Italians. Again, many English have florid skins. By tradition the Mongoloids are yellow but many show a combination of reddish brown and yellow. In the case of the American Indian the reddish brown is often prominent, which may account for the popular notion of the "redman." However, the Indian usually preferred to smear his face with red paint which of itself could have been responsible for the idea. In general his body color is a reddish yellow plus brown.

To accurately record skin, hair, and eye color, one needs a color chart. Even then the readings must be taken from the same parts of the body to be comparable, because of wide variation between face, hand, underside of the arm, etc. One of the color scales used is known as the Von Luschan Scale. It consists of small rectangular pieces of colored porcelains, numbered, ranging from one, which is creamy white, to thirty-six, deep black. The chief weakness of this device is that none of the glassy porcelain tablets look like skin, yet it is the most convenient color scale yet devised, for the colors are constant. In practice the anthropologist records the number corresponding to the color chosen.

A more modern and less arbitrary method is to use a color top standardized by Milton Bradley Co., Springfield, Mass. When the top is spun the separate color sectors fuse into a single color. Skin can be approximately matched by combining four colored paper disks, white, black, yellow, and ox-blood red. These it happens are the chief pigments in the skin. The disks overlap in such a way that the relative amount of each color can be regulated and the proportions read off as degrees of a circle.

COLOR TOP RATINGS OF SKIN COLOR

	<i>Black</i>	<i>Red</i>	<i>Yellow</i>	<i>White</i>
Italian	25	32	18	25
English	13	33	17	37
Australian natives	67	23	5	5
Negro	77	15	3	5
U. S. Indian	37	40	10	13
Japanese	20	33	14	33

The advantage in the use of the color top is that it analyzes the color into the primary colors entering into the combination. However, this is not really accurate, for the colored paper disks reflect some light of other colors, yet this is constant and so can be corrected in the final result. The readings in the table are based upon single individuals and so are not necessarily representative of the groups measured. Notice, however, the differences in the percentage of white and black in the types represented.

Eye color is usually recorded as black, dark brown, medium brown, light brown, gray, green, blue-brown, gray-brown, dark blue, light blue. The most satisfactory way is to make up a series of glass eyes of these colors for reference when recording eye color.

It will be impossible to discuss all the standardized methods of describ-



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Fig. 2. Measuring Points and Measurements of Width: gl = glabella; na = nasion; sn = subnasale; gn = gnathion; eu = euryon; zy = zygion; al = alare

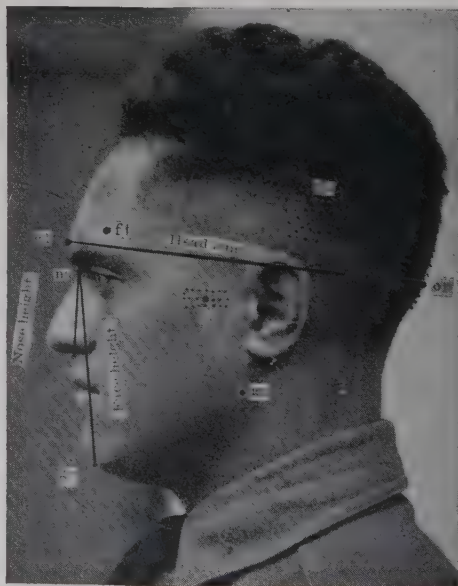
ing individuals when studying living peoples, but we shall continue an enumeration of some of the most significant.

THE HEAD AND FACE

If one looks down upon a series of heads from above, they will seem of various oval shapes. Measurement is generally used to describe them by taking the maximum length and width (Figs. 2 and 3). The cephalic index is obtained by dividing the width of the head by the length; for example, for a head 140 mm. wide and 200 mm. long, the cephalic index is 70.0. This would be an unusually long head such as may be found among some of the Papuan tribes of New Guinea. At the other extreme are the Laplanders, credited with a cephalic index to 87.4, a very round head. The

Negroid group as a whole tends to be long-headed, but the Caucasoid and Mongoloids vary so widely that they cannot be consistently assigned a cephalic index.

As for the face, the nose may be wide and large, as among Negroids, or narrow and high as among Caucasoids. Another way to describe noses is to look at the nostrils; those of the Negroids are horizontal, those of the Caucasoids are vertical, while many of the Mongoloids are intermediate. Many Mongoloid peoples have what is often called a slanting eye. The eye does not slant but has a fold of the upper lid which gives such an appearance (Fig. 5). Some Eskimo and a few American Indians have a moderate trace of this fold. Naturally the Mongoloid fold is one of the



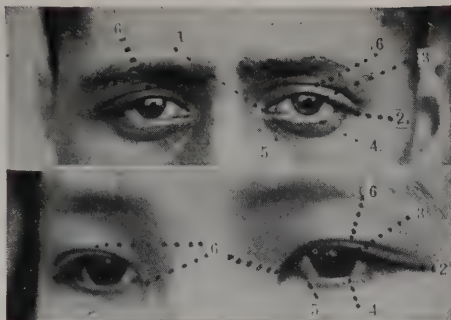
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Fig. 3. The Landmarks and Length and Height Measurements: gl = glabella; op = opisthocranium; na = nasion; sn = subnasale; gn = gnathion; eu = euryon; zy = zygion

striking characteristics of that people which taken with their straight black hair and round heads serves as a practical classification.

Curiously enough, most of the Mongoloids, including the American Indians, have shovel-shaped upper incisor teeth (Fig. 4). This is a marked characteristic linking the Indians and the Mongolian peoples of Asia. Another similarity between the two is the prevalence of wide faces, sometimes erroneously spoken of as high cheek bones, because the wide face makes the cheek bones prominent.

Stature is sometimes used as an index of body size. Enough sample measurements have been made to reveal marked differences in this character. The smallest people are the pygmy tribes of Africa, averaging 137.8 cm. (about four feet six inches). Among the tallest are the Scots of



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Fig. 5. A Caucasoid eye compared with a Japanese eye to show the structure of the Epicanthic or Mongoloid eyefold. 1. inner canthus; 2. outer canthus; 3. free upper lid; 4. free lower lid; 5. caruncula lacrimals; 6. the fold in the skin which covers the inner canthus

North Scotland, averaging 179.2 cm. (over six feet four inches). There is great variation from people to people and from tribe to tribe, so that no characteristic stature can be assigned to each of the three main divisions of mankind, the Negroid, Mongoloid, and Caucasoid. Nor does the average stature seem to be permanent, since it has been proven that Europeans settling in America become certainly taller in the third generation and even change their head form. The causes for this are conjectured to be environmental.

INBREEDING GROUPS

Man is a social mammal and this being his outstanding characteristic is bound to be of the utmost practical import in any useful scheme of classification. We take for granted that the population of the world is grouped into national units, independent, free agencies. Primitive peoples live in smaller units, or nations, than is the case with civilized peoples. These primitive nations are



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Fig. 4. A comparative series of upper incisor teeth showing examples of the shovel shaped type frequent among Mongoloids and American Indians

usually spoken of as tribes. In the United States, for example, the rule was to treat each tribe as an independent nation unless it acknowledged control by another tribe. In other words, the colonists accepted the statements of the Indians themselves as to how many and which particular camps or villages constituted an independent political unit. The observer would then look at random samples of individuals in a given nation to determine what may be called the biological type.

This is justifiable only because marriage is usually within national lines, especially among primitive and ancient peoples. It has always been thus, so these independent political units, tribes, or nations are inbreeding. The biological principles of heredity are such that each tribe is destined to evolve a type or race of its own. These are made up of family lines, the constant intermarriage of which tends to produce a tribal or national type. In other words, individuals in a given group look alike. For example, if we look at a series of Eskimo photographs, we soon come to have in mind an Eskimo type of face by which we can identify other photographs. The same will be true for most any other tribal group. These are qualitative judgments, which means simply that we may find it difficult to explain what characters we use in reaching such conclusions. For all that, the distinctions are real ones.

When we wish to be scientifically objective, we try to define this tribal or national type by designating certain peculiarities. Thus the individuals examined may, for the most part, have gray eyes, a special form of nose, squinting eyes, the inner corner of

the eye (the canthus) may turn downward, the faces may seem large, the lips full, etc., but for all this, two national groups may correspond closely in these few characters and still look different. It is the sum of all differences that finally combine into one's conception of the type, all of which are passed on from parent to child.

If there were no inter-tribal characters there would still be close similarities between some social groups and others, because one might well be primarily the offspring of the other. A primitive tribe may increase in population until it can with difficulty maintain itself as a unit, whereupon it divides into two parts, one—or sometimes both—of which seeks a new home. They now begin to have separate and different histories, change some of their ways of living, drift into speech changes, until finally the process of heredity changes the appearance of the tribe members. However, since they had a common parentage at the outset, they will continue to look more alike than different. This will explain how it came about that Mongoloid people spread over a large part of Asia and the two Americas. Yet, the modern Chinese, Koreans, Japanese, and Mongoloid Siberians have their differences, as do the American Mongoloids or the Indians. The terms Mongoloid, Caucasoid, and Negroid designate the basic ancestral stocks from which many tribes and nations have sprung by tribal subdivision. Our difficulty in discovering the true relationships of tribes and small nations is that their history is lost, the earlier social inbreeding groups having disappeared or changed in appearance. So we depend upon those characters which happen to

have remained relatively uniform. Thus straight black hair, yellow-brown skin, wide faces, eye tending to show folds of upper lid and shovel-shaped incisor teeth are taken to mean that the tribes or nations concerned descended from a common ancestral group, which we have given the general term Mongoloid.

To summarize this long discussion, the simplest way to classify biological types of living man is to enumerate the independent original social groups or tribes; then to classify these groups into larger classes and divisions. As classes become larger they will show fewer characters in common but naturally these will be the most dominant in their transmission by heredity. What is called physical anthropology in the United States is devoted to the anatomical descriptions of these tribal and national groups, and to their classification by similarities of their physical characteristics.

CLASSIFICATION BY LANGUAGE

We have noted that when tribes and nations separate to form new tribes, they carry with them their ancestral appearance, which, though it eventually changes, still shows resemblances to the parental type. In the same way the new tribe takes with it the ancestral speech, but once it lives apart, speech begins to be different. This enables the language expert to not only classify tribes and nations according to their speech, but to arrange them in lines of descent. When the differences in tribal speech become too great, the tribes are considered as belonging to different families. For example, the dominant



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Fig. 6. Long-headed, or dolichocephalic, types (left) have the skull long from back to front, and rather narrow; while short-headed, or brachycephalic, types (right) compensate for the shortness of the skull by added breadth

languages in the nations of Europe (except Finland and Hungary), and Armenia, Persia, and part of India, constitute a family known as the Indo-European. The Finns and Hungarians, as well as the Turks, belong to the Ural-Altaic family which covers most of Asiatic Russia. Next we note the Sinitic family, including China, Tibet, and Burma. There is the Semitic family, which covers Palestine, Arabia, and large areas of North Africa. Most of the Negroes in Africa speak languages of the Bantu family. Civilization seems to reduce the number of languages, either by exterminating many tribes or forcing them to learn the standard language of the conquerors. Writing, of course, helps to fix and standardize speech. Writing also preserves languages, as in archaeological inscriptions on clay and stone. Such give the earlier

forms of many languages still spoken in variations, thus making it easier to trace connections and origins in the development of the language family. On the other hand, under primitive conditions, without writing, speech could change often and without knowledge of the older forms of the language. The situation in primitive languages, the extinct dialects of which are lost beyond recovery, presents a situation like that of a tree which, but for the topmost twigs, has disappeared. We may not be able to determine if the surviving languages are all parts of the same tree, as in

the case of the Indo-European languages.

North and South America were once supposed to be the home of 169 families of languages which had no visible ancestral relations to each other. This is generally explained as due to our lack of intimate knowledge of these languages. For example, one of the great authorities in languages, Dr. Edward Sapir, considers that the 56 supposed families in the United States and Canada are really members of eight super families. The probabilities are that even this small number will be greatly reduced.

ETHNOLOGY AND ARCHAEOLOGY

ONE important division of anthropology is ethnology. Usually this is considered as covering studies of living man about whom we possess written information about their manners and customs, their speech, habitat, etc. Sometimes this study is spoken of as culture, again as social anthropology. Archaeology is a method of reconstructing the lives of extinct peoples, or such as are not recorded in literature. Since these reconstructions are in terms of what is known about living peoples, they may be considered as contributions to culture and social anthropology. However, some of the methods employed by archaeology give time relations, or relative dates, thus recovering the lost history of mankind. This will be discussed later. Ethnological research is conducted by visiting living tribes, observing their modes of life, recording their speech, and preparing descriptions of their behavior and beliefs. Museums collect the objects they make and use, with photographic records of their appearance, ceremonies, and home life. The study of such data results in a body of knowledge serving as a basis for the interpretation of man's past and present.

For example, anthropology, supplemented by history, presents a simple but basic outline of the evolution of human life and achievement, chiefly in terms of inventions to assist man in making greater use of what nature provides. This outline, with approximate dates, is given in the following table.

AN OUTLINE OF MAN'S
CULTURE HISTORY IN
THE OLD WORLD

1. The Age of Hunters
50,000-9000 B.C.
The important inventions were fire, stone tools, the lamp, tool handles, clothing, cooking food, burial of the dead, drawing and painting, religion, and social organization.
2. The Farmers and the Herders
9000-3000 B.C.
The important inventions were agriculture, domestication of the ox, horse, and sheep, the plow, the wheel and wheeled vehicles, the sailing boat, pottery, weaving, irrigation, fermentation, copper, bricks, the arch, the initial steps in inventing a solar calendar, writing, numeral notation, and bronze.
3. The Age of Cities
3000-500 B.C.
Few outstanding inventions were made in this period but those previously made were intensively exploited. Notable inventions were decimal notation, smelting iron, alphabetic writing, the aqueduct, coinage of money, taxation, and military equipment. Also outstanding was the development of wealth and its social accompaniments.
4. The Age of Knowledge
500 B.C.-1500 A.D.
Most conspicuous contributions were methods of gaining new knowledge, literature, science, gun powder, and printing.

5. The Industrial Age

1500 A.D. to the present.

The great achievements are in steam and electric power and their many applications, telegraph, railroads, radio, airplane, chemical products, serums, vitamins, etc.

It will be observed that some basic inventions were made by the early hunters but that the period of prolific invention was the second relatively short period of about 6,000 years. It is safe to say that most of the fundamental inventions and ways of living were established at the end of this period, about 3000 B.C. Nothing like this period was known before nor since. Here is when the foundations to civilization were laid and most of our ways of living in the present are due to the expert exploitation of these fundamental inventions. In the main, these new ways of living, based upon the successive inventions, were accompanied by rapid increases in population, larger social and political units, and so more complex societies. There were no great populations in the age of hunting, no large towns, no cities, no nations. There is no reason to suspect that France had a population of more than 5,000 persons in the late Stone Age, nor more than 25,000 in 3000 B.C. Naturally this is a guess, but in the late Stone Age the climate of France was near that of the Arctic today and could not support many thousands of persons. It is estimated that the entire Arctic area of Canada, an area even larger than the whole of France, never contained more than 5,000 Eskimos. It is easy to see that a people living entirely by hunting would require a good many square miles for their

exclusive use. Sir Arthur Keith once estimated that in a very favorable country a tribe of 50 people would require an area of 100 square miles, and that at this density the population would not increase because starvation would keep the hunters down in numbers. So if France had a genial climate it might have produced sufficient wild food to have supported 100,000 people, making no allowance for waste lands. Thus it seems safe to say that at no time during the hunting age could France have supported a population of as much as 100,000, the chances being that a much smaller number would be nearer the truth. On the other hand, once agriculture and domestication came into general use, the population could have been greatly enlarged.

The Age of Cities was the beginning of great nations. Rome, for example, is called a city-state because the citizens of one city and its surroundings dominated and ruled the empire by organization, commerce, and by maintaining large armies. Under such conditions the population would rise to approximate the ability of the government to feed it.

THE HUNTERS AND GATHERERS OF WILD FOODS

The Age of the Hunters and Gatherers seems to have reached a moderately advanced level of living some 50,000 years ago. What knowledge we have of this age comes chiefly from western Europe.

Back in Chapter 25 we noted how the standards of living in the successive Stone Ages rose as new inventions appeared and as the characteristics of man changed. We saw how the displacement of Neanderthal man



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Fig. 1. Restoration of a Lake Dwellers' village of the age of farmers and herders

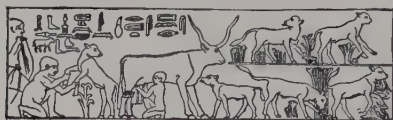
by Aurignacian man made many changes in the way of living, especially the inventions which accompanied the evolution of art. After about 40,000 years of well-organized hunting and gathering cultures, man was equipped for that kind of life: he possessed efficient tools and weapons, clothing, housing, household furnishings, rules and disciplines for living in communities and tribes, enjoyed art, and maintained a religion with accompanying ceremonies. We can be sure he had a servicable language and a wide knowledge of nature, climate, and animal behavior. There were pure hunters and gatherers in Australia, for example, when Europeans first looked in upon them, who in some respects did not possess as advanced a standard of living as the Magdalenians, though they lived in a less harsh environment. In North America, too, a large number of tribes were non-farming hunters and gatherers living modes of life not much different from what the Stone

Age men were enjoying, particularly tribes of the Canadian forests, where the winters were severe. This means that a purely gathering and hunting mode of living limits the participants to a generalized standard of living, as in small, independent communities, without the organized activities that may be met with in agricultural or industrial societies. The correct assumption seems to be that many of the other known forms of life are incompatible with a hunting and gathering economy.

THE FARMERS AND THE HERDERS

The most outstanding additions to culture in the second age of man are agriculture, irrigation, ceramics, domestication of animals, weaving, the wheel, the plow, metals, writing, masonry, and sailing vessels. It will be noted that if these are added to the inventions made by the hunters, the list comprises the foundation of civilization. As time goes on, these basic inventions will be elaborated, becom-

ing more mechanical, but not very different otherwise. Another good name for this period might be the Golden Age of Inventions. All of those listed are of first importance so that it would be difficult to agree as to the outstanding one. We have sug-



Breasted

Fig. 2. An ancient Egyptian drawing of a milking scene

gested the above heading to this section because it represents food and transport, both of which are requisites to an increase in the density of population and the security necessary to the maintenance of a more complex form of society than prevails among hunters.

AGRICULTURE

No one seems to know how, where, or when the first steps in agriculture were taken. It seems likely that in several places at different times the initial steps were inaugurated. Among a people as ingenious as the late Stone Age hunters, who supplemented their meat diet with seeds and wild grains, the suggestion of planting and tending seems inevitable. From wild, unplanted grain to planted crops would seem a simple step. First, however, there must be a favorable environment, and since the later Stone Age was in a time of Arctic climate, it is inconceivable that agriculture should develop, for food plants were rare. Yet, wherever seeds of grasses and legumes grow wild, their food value is sure to be recognized. Not only are the seeds good food, but they can be stored for a long period of time.

The great food plants of the world are the cereals, wheat, rice, and maize. There are others of somewhat less importance, though still significant. The first three mentioned each had its own area of origin and exploitation—maize exclusively in the Americas, wheat in the Mediterranean area, and rice in southeastern Asia. We still think of these great geographical areas as their centers of exploitation, even though the three grains have been carried to most all parts of the world. Perhaps we should add that millet was largely exploited in Africa.

The habits and yields of these plants were greatly changed under domestication. Maize was so greatly changed that there are still differences of opinion as to the identity of the wild ancestor, though the best guess is that it is wild pod corn which originally grew in Argentina and the surrounding grass lands. But it was in the Andes that it took the form of maize and thence spread over a large part of both South and North America. Its merits, aside from being a good food, are its hardiness, its generous yield, and its capacity for safe



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Fig. 3. Indian corn or maize

storage. Europeans quickly adopted it, carried it to all parts of the world, and it is still one of the great crops of civilization.

Not so long ago the wild ancestor of wheat was found in Asia Minor, so solving that problem. Further, this is the region where wheat first appears in history and rises to a high level of economic importance. The history of rice is obscure, but India is regarded as the most likely region of its first cultivation. There is some reason to think that wheat is the older cereal, that it found its way into India from the west, but that parts of India were too wet and tropical for wheat, so the wild rice which abounded in that area was domesticated as a substitute. This is probable because the methods used in rice production are similar to those used for wheat. Once rice was domesticated it might easily

have spread over eastern Asia and into the islands of the Pacific, wherever the climate and the soil were favorable.

The term millet applies to a number of different grasses. The true millet (*Panicum miliaceum*) may have preceded wheat in the Mediterranean area; sorghum and Kaffir corn were common in Africa and another form of millet (*Eleusine coracana*) was raised in China and surrounding areas. The millets are good grains, though inferior in food qualities to wheat, maize, and rice.

The only other food plants of importance are the roots, such as manioc, yams, potatoes, and taro. In origin, these are associated with primitive tribes rather than with those approaching the level of civilization, though in modern times civilized peoples have exploited some of them.



Oriental Institute, Chicago

Fig. 4. The use of the plough in ancient Egypt

Most of these foods grow best in tropical, moist, fertile lands, as manioc in South America and Africa, and taro in the islands of the Pacific. Their cultivation is easy since they require but little care and yield generously. Some observers suspect that the ease with which they can be grown and their rich return in food, tended to perpetuate the primitive forms of society cultivating them. This may not be the whole story, but does suggest that the old theory that agriculture arose first in deserts or other unfavorable lands, presents difficulties, as against the idea that some of the root plants were the first to be cultivated.

DOMESTICATION

There are no facts indicating that animals were domesticated during the Age of the Hunters. Near the end of that period some cave paintings in Spain suggest the use of dogs in hunting but even this indicates that the spread of the dog over the world came during the Age of the Farmers and Herders. Naturally, once domestication was an accomplished fact, the use of the dog could easily have spread to surviving hunters who possessed no domestic animals. The ancestor of the domestic dog is uncertain, but zoologists consider him originally a member of the wolf family. Yet the dog belongs with house pets, and was, perhaps, the original member of that interesting fraternity. The other important domestic animals are cattle, sheep, goats, horses, asses, camels, and pigs.

The history of these animals is far more obscure than that of domestic plants. Yet in one respect the problem is simple, for it is mainly a development in the central part of the Old

World. The only similar case of domestication in the New World is the use of the llama in South America. The time of domestication in the Old World is well within the Age of the Farmers and the Herders since all the historical and archaeological data we have shows that all the animals we have named were rather widely dispersed before 3000 B.C. The pig, sheep, and goat were food animals, whereas the ox, ass, horse, and camel were primarily beasts of burden, though they had food values also.

Turning to the first class, the use of the pig seems to have spread rapidly. Several wild species have survived until recent times, but the problem of origin is complicated because the domestic pig runs wild at the first opportunity. Where the domestication of this animal began is uncertain, nor can anyone say that a single species was taken as the source of the original stock. Pig bones appear in Lake Dweller sites of Europe, but this may have been later than 3000 B.C. and so not within the age we are now discussing.

Two species of wild sheep have been designated as the ancestors of modern sheep, the original home of which lay between southeastern Europe and India. The bones of sheep appear in the oldest ruins of Asia Minor, which suggests that they were first tamed before 3000 B.C. In fact, at the end of the cave period in Spain, pictures were painted showing cattle and women together as they might be assembled in herding. Cattle bones appear in archaeological sites of 3000 B.C. The early Egyptians possessed several breeds of cattle, hornless, short horn, and long horn, and this at such an early date that domestication must have been under way for

a long time. Even if these were originally wild species of cattle, no longer extant, their domestication must have taken place long before. That the use of the ox for transportation was ancient, is shown by the early representation of the cart and the plow. So in general, the suggestion is that the ox was domesticated, either in north

Africa or in western Asia and diffused over the central part of the Old World.

The horse and the ass belong, primarily, to the dry, grassy plains of western Asia, where they were probably first domesticated, except that the north African ass can make the strongest claim to being the ancestor of the domestic breeds. The horse, on the other hand, makes a good claim to an Asiatic origin because it was from thence that horses were introduced to the historic nations. The first domestic horses were descendants of the Przewalski type of horse, which survived in western Mongolia almost to the present. It is supposed to be of the same species as was hunted by the Stone Age men in Europe. There are archaeological sites with the bones of cattle but with none of the horse, so there can be little doubt that the domestication of cattle has priority, that the ox was probably used with the cart and the plow before the horse was available. The domestication of the camel, however, came late, probably not before 1000 B.C. in the countries where it was found.



Breasted

Fig. 5. Ancient representation of a hunting scene showing dogs accompanying the hunters

One significant conclusion from all this research is that once domestication was begun it spread rapidly. All kinds of animals were experimented with, even elephants. The use of milk also came early, as did the cart and the chariot. We may never know which animal was ridden first, but once the custom of riding one species was established, experimentation with others followed quickly. The same would be true of the cart, plow, and milking. The pattern for the use of one animal would be extended to any others available.

THE WHEEL

It would be hard to overestimate the significance of this fundamental invention since it forms the essential mechanism for moving objects and for transmitting power. Without it our way of living could not be conceived and there could have been nothing like an industrial age. Probably the earliest application of the wheel to mechanical devices was the potter's wheel, an invention of the Old World which never reached the New, but which appears early in eastern Asia,

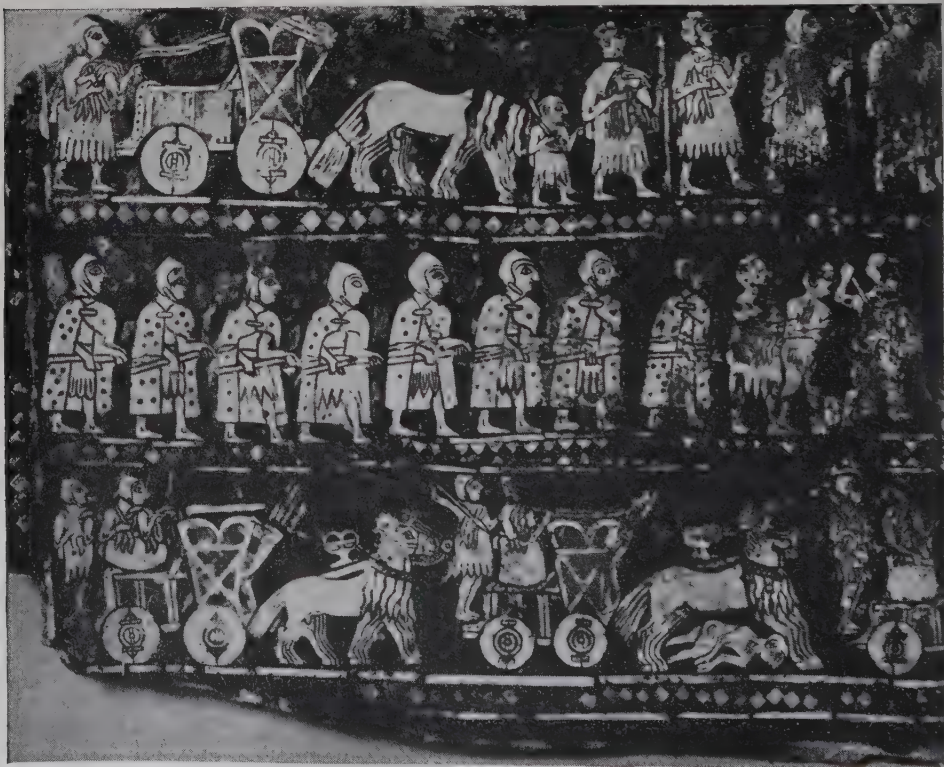
possibly as early as the cart. Respecting the cart and the chariot; no one knows whether the first vehicles had four wheels or two. One of the early carvings of a Sumerian vehicle has four wheels, whereas most of the later representations are true chariots. The wheels in this instance are solid, but made of boards joined together, probably overlapping, or two ply, but delicate, four-spoked chariot wheels soon appear. As with other inventions in this age, progress was then rapid.

Another interesting point is that these earliest representations show the use of asses and horses instead of oxen. However, the pictures represent kings and their exploits in war

and hunting, situations in which the ox would be too slow. Unfortunately, most of these pictures belong to the Age of Cities, in which these inventions are shown in such an advanced state, that we assume their origin in the preceding age.

CERAMICS

The discovery that heat will produce a chemical change in clay, rendering it hard and insoluble in water, and the exploitation of that knowledge, was one of greatest importance. Ceramics and glass play so large a part in our everyday life that we often overlook their importance. Again the original place and time of origin is



University Museum, Philadelphia

Fig. 6. Primitive illustration showing the use of four-wheeled vehicles drawn by horses or asses

obscure. Yet the indestructible nature of pottery fragments guarantees their appearance wherever people made or used fired vessels. There is some reason to believe that this discovery was earlier than agriculture, and if so, initiates the age we have designated as that of the Farmers and Hunters. In semiarid countries, adobe and sun-dried bricks were used as building materials, especially where good stone was scarce. The use of burned bricks appears early and was greatly exploited in the Age of Cities. Even books and documents consisted of fine clay tablets.

Later, pottery became a medium for art, probably because of its great plasticity. The early invention of painted designs on the surface of pottery, using materials made indestructible by firing, has given us minute knowledge concerning early habits of living, so enabling historians to fill in many gaps in our history of the ancient past.

WEAVING

We have no evidence of weaving in the Stone Age hunting period. There may have been some attempts at it, the first steps may have been taken at that time, but no examples have survived. It seems curious that if baskets were made some trace should not have crept into the paintings and charred fragments found in the many thousand cubic yards of debris examined, but so far the record is silent. It is likely that sinew thread was made for the needles first used by the Solutreans, in which case the principle of spinning was understood. String is such a useful device that it should have been discovered early in man's evolution, perhaps long before weaving. However, mats and baskets



Museum of the American Indian

Fig. 7. A pottery vessel from the Zuni Indians, New Mexico, a modern survival of a prehistoric craft

were probably the earliest forms, but when traces of them appear in the Old World they are accompanied by evidences of ceramics and agriculture. True cloth appears in Lake Dweller remains and seems to have been known in early times in eastern Asia. Hence, one can set down weaving as one of the great complex of inventions characterizing the Age of the Farmer and the Herders. The weaving of flax appears as early as 8000 B.C., in Egypt; cotton, in India, as early as 3000 B.C. Cotton was woven in the New World also, but it has been shown that the plants are not identical so the discovery in the New World was probably independent of Old World influences. The Old World appearance of wool is uncertain, but sheep were domesticated before 6000 B.C.

At first the making of thread was by hand twisting. Even now many backward peoples in the world are

spinning good thread without using spindles, simply rolling the fibers by hand. Nevertheless, spindle whirls appear in archaeological remains of antiquity, suggesting the invention of that instrument in the earliest stage of weaving. The first looms seem to have been a single bar of wood hung or supported by two forked posts. The warp threads hung down from this and the weaving began at the top. Later, perhaps before 3000 B.C., a second bar was added, making a rectangular loom, or a two-bar loom.

WRITING

The drawing of pictures pointed the way to writing, and the earlier forms of picture writing seem to have preceded true syllabic and phonetic writing. Sumerian writing, preserved on clay tablets, appears at the outset in their earliest archaeological remains. It went through a rapid period of development, which can be observed in the comparison of clay tab-

lets of successive ages. The interpretation of these changes is that at the outset writing was confined to lists or inventories of property, chiefly memoranda by priests in the temples to specify the objects needed for food and religious sacrifices. True phonetic writing seems to have been invented by the Seirites, who were trying to adopt the Egyptian mode of writing to recording events in their own language. This was about 1800 B.C., and the place designated as the site for the origin of the invention is the Sinai Peninsula at the head of the Red Sea. The obvious virtue of the phonetic alphabet is that it made printing and mechanical writing practicable. Yet the real advancement of writing falls within the Age of Cities, though its beginnings lie in the previous age.

SOCIETY

In the case of the Hunters, we found the populations sparse and the camps composed of a few families. Further, the places of residence were not fixed but easily shifted in response to climatic, seasonal, and faunal changes. Large game animals are apt to be wanderers, requiring the hunters to follow them, even though they circle about instead of drifting over a large part of a continent. Even within an area so small as France, many localities were doubtless free of game during part of each year. But in the following period the situation changed. Farming and domestication increased the food supply greatly and reduced the threat of starvation to a minimum. Since the area required to feed a community was greatly reduced, the villages could increase in size and the distance between them become less than was

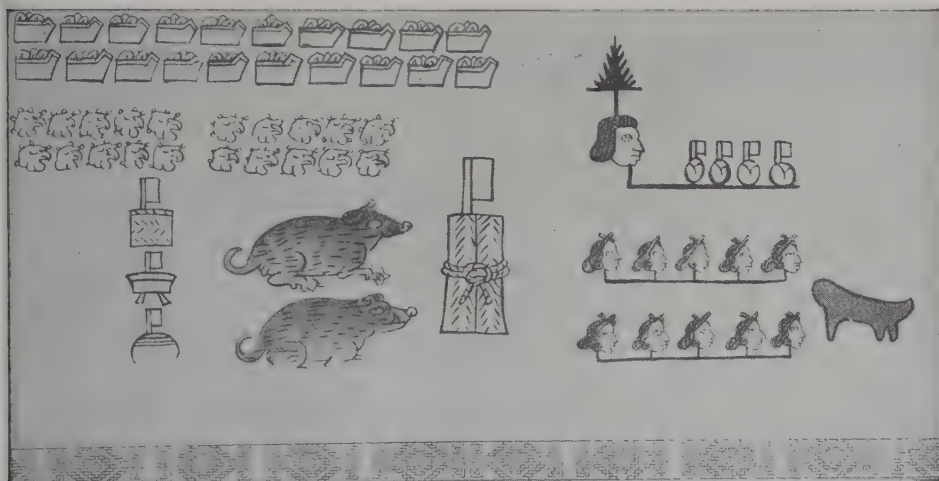


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Fig. 8. Survival of the earliest known form of weaving in New Zealand

the case with hunting camps. Finally, the locations of these villages were more stable. All of which resulted in larger populations and larger social units. Teamwork would now be limited chiefly to defense and government. With more people in the village and ampler food supplies there can

horse gave increased power for agriculture as well as for transport. The improvements in boats and the use of sails gave impetus to the use of waterways wherever possible. Communication between distant villages was far easier than before. There was plenty of fighting, as much as, if not more



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Fig. 9. Aztec Picture Writing. This is the record of tribute exacted from the pueblo of Coatlalpan by the Spanish conquerors

be more specialization, and more invention. Economic prosperity seems to have released new energy for new inventions, both mechanical and social. There was a quick rise in the standard of living, with houses becoming larger and the family equipment increasing in quantity. At the outset there would still be more or less hunting, hence the tools used in agriculture for the handling and storing of crops, and the equipment for herding and housing animals would all be extra property required for living up to the contemporary standards of the new age.

Transportation was greatly augmented and the use of the ox and

than, formerly, since surrounding non-agricultural tribes would raid the villages for plunder and poach on the herds of those who raised pigs, cattle, or sheep. Rival villages would fight over the possession of the best lands. Eventually this would lead to fortified villages and the federation of villages into tiny states. The hereditary rights of kinship groups would evolve, carrying with them privileges and rank, expressing themselves in clans and chieftainships. The medicine men, or shamans, would expand their power and rituals, setting up ceremonial shrines which would eventually evolve into temples as the society further evolved.

The powerful chief of a large village would begin to take on the functions of a king, maintain a group of fighting men for police duties, for defense as well as offense. War for profit in goods and slaves would soon be recognized and regularized. At the same time new inventions were doing their part in increasing the size of villages and heaping up reserves of food and other useful materials. As soon as the idea got abroad that a chief of a few villages could increase his power by subjecting other villages, requiring them to pay tribute in food, raw materials, and labor, a movement would start for even larger villages, resulting at last in the building of cities to exploit and rule over large areas and to profit by trade with distant lands. Thus the accumulation of wealth and man power opened the way to a new age, the Age of Cities, and led eventually to empires.

AGE OF CITIES

We should not expect sharp breaks between these so-called ages of man, for they shade gradually from one into the other. It is only because cities of respectable size begin to appear around 3000 B.C. that we speak of a new age. These cities grew up slowly in the preceding period among the larger villages of the farmers. Possibly they first came into existence in the most fertile spots, as the deltas of great rivers, such as the Nile and the Euphrates, locations where a great deal of food could be produced. That they grew in part by conquest is evident, as when surrounding villages were forced to unite under a strong, ambitious leader who, with their combined resources and man power at his command, undertook to create a master city. About the only

new problems would be those of housing, feeding, and governing a large city population. Yet most of these problems had been solved in some fashion by the earlier village dwellers. All the necessary increase of organization for controlling the capital city and its dependent villages would call for the improvement of writing, which required a number of inventions of writing materials, the standardization of measures and the accompanying mathematics, the increase of commerce to bring to the city materials not locally available, to provide a healthful water supply to the city, to build walls of defense, to build great temples consistent with the power and grandeur of the king, and to improve the weapons used by the army.

This is but a crude outline of what archaeology and ancient history tell us did happen in the Age of Cities. New inventions were made but for the most part the kings and their staffs were exploiting the inventions and discoveries made in the preceding age. For example, aqueducts were invented to bring fresh water to the cities, but masonry, the use of bricks and stone in the needed forms, had been developed before. The arch, however, seems to have come into use during the Age of Cities. The working of metals was intensified, especially bronze, which gave tools far superior to stone.

The increase in property and the protection of it required accounts and records to be kept, and this in turn required writing. The mere matter of going abroad for the exchange of goods demanded written messages, orders, and receipts. Writing quickly became a profession confined to a small class, "the scribes." Often the



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Fig. 10. A restoration of the Plaza in Mexico City before its capture by Cortez, showing the temples and altars for human sacrifice

king himself could neither write nor read what was written. To know how much grain must be transported and stored to feed the city required calculation, not only to estimate the weight of the grain, but to furnish dimensions for the building of store houses. This stimulated the invention of mathematical techniques and a concomitant class of professional calculators.

Another custom which took definite form in this age was the exacting of tribute, usually levied in goods, of specified amounts and kinds. This procedure guaranteed to the inhabitants of the city a comfortable living and to the king a surplus for his armies and laborers and for exchange in trade. To express this in modern terms, one important invention in this age is taxes. The coinage of money was another significant invention which enhanced and standardized the value of gold and silver. Wealth, its

significance and potential power, first comes to notice in these old cities, accompanied by the inverse of it, poverty. Labor became of importance and the distinctions between skilled and unskilled labor were demonstrated. Kings exchanged or bartered both kinds of labor, or at least condoned such exchanges. Another city might be in need of metal workers, weavers, or stone carvers, securing them from a city with such labor to spare. These exchanges would include the scribes and the calculators, as well. This helped to diffuse the knowledge and inventions of one city among all the cities of the Old World.

Since special kinds of metals, wood, shell, dye stuffs, etc., were needed for many of the objects to be made by these imported laborers, and craftsmen were found in but one or two localities, commerce became important. Men were stimulated to explore surrounding countries for new sources

of supply. If these desirable commodities happened to be found in thinly populated localities or in countries occupied by primitive, backward, unorganized peoples, colonies would be established, composed of laborers to operate the mines or cut the timber needed. A small garrison might be added to defend the settlement and maintain order. Thus began a system by which the great cities and their successors, the empires, extended their control over large areas, even of continental size. The first great empires took the form of super city-states, from which have evolved the great nations of our time. In the Age of Cities the building of temples, palaces, memorials, tombs, roads, aqueducts, irrigation systems, fleets of ships, etc., were in the nature of public works constructed by the king with taxes and conscripted labor. Most of these radical changes have their origins in the agricultural villages, or towns, with their outlying lands, or townships, culminating in super towns or cities, with societies

organized according to the same pattern. Most of this pattern still functions in modern societies as seen in the integration of cities, towns, and country.

Some of the outstanding cities of the Old World, with their approximate dates, are given in the following list.

SOME IMPORTANT CITIES OF THE OLD WORLD

Babylon	3790-1750 B.C.
Ur	3500-2100 B.C.
Troy	3000-1500 B.C.
Assur	2900-606 B.C.
Akkad	2500-2300 B.C.
Memphis	2500-1100 B.C.
Thebes	2500-600 B.C.
Cnossus	2000-1200 B.C.
Nineveh	705-681 B.C.

PARALLEL DEVELOPMENT IN THE NEW WORLD

Before the empires of the Old World discovered the Americas, the New World aboriginal inhabitants seem to have gone through a similar development. They were so greatly isolated from the centers of civilization in the Old World and show so little evidence of direct influence from them, that anthropology regards their growth as an example of independent development. In 1492 the New World presented people living under the three ages of man so far outlined—hunters, farmers, and city-states. Even at that time there were hunters and simple farmers in the Old World, though the great cities had become parts of empires or kingdoms. In Mexico and Peru were great cities controlling large areas, well organized and efficiently governed, reminding us of the Age of Cities, but these New World cities did not come into being



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Fig. 11. Bronze bracelet and rings which were used as money by the Lake Dwellers of Switzerland

until the first centuries of A.D. time. Because of these differences in time it is difficult to see how the successive ages could have been transferred directly from the Old World. Had these changes in modes of living been brought about by invasions from the Old World such changes would have been nearly simultaneous.

To even relatively date the three ages in the New World is still difficult, but so far the evidence points to gross time differences. Thus the usual estimate for the appearance of man in North America is post-glacial. Whereas we found man beginning his career as a hunter, using fire, inventing art, etc., while living before and during the last glacial period, New World man began his career here after that period, that is, about 10,000 to 15,000 years ago. The beginnings of New World farming go back little further than 3000 B.C., which is the date for the Age of Cities in the Old World. The surviving pueblo Indian villages in New Mexico and Arizona are examples of agricultural villages like those of the Old World, each independently controlling its outlying farm lands, and the origins of these villages have been traced by tree-ring dating from their simple prototypes about the beginning of the Christian Era to their culmination in large towns around 1200 A.D. They had not achieved great cities even in 1492. The mound builders had large farming villages when the greatest earth works were constructed, but these are believed to have culminated about 1200 A.D. and to have disappeared by 1492.

In Mexico and the Andes the story was different. Archaeology tells us that the period of farming villages did develop into an Age of Cities, real



Wissler

Fig. 12. Map showing the distribution of the three ages of man in the New World in the fifteenth century. 1, Hunters; 2, Agriculturists; 3, City-states

city-states, and eventually into empires of a kind, to be overthrown by the white invaders from Europe. Their inventions seem to have paralleled those of Europe in a general way. With farming came ceramics, weaving, stone and adobe building, and the domestication of the llama. As we have noted, an important cereal, maize, was produced, which was the food base to the subsequent city-states. Metal work in gold, silver, and copper was advanced until, in the Age of Cities, bronze was discovered and used for tools and weapons. Curiously enough the New World did not discover the wheel, nor had they, by 1492, come to recognize iron. They were clever in ceramics but did not discover glass; good builders but failed to construct the true arch. Yet, like the great cities of the Old World, they used aqueducts, and built roads

and bridges. Having no wheel they developed no draft animals. Writing was accomplished in Mexico and sufficient mathematical skill developed to satisfy current needs. Their astronomical knowledge was far from contemptible. They cultivated and wove cotton, producing cloths of exceeding fineness and color. Temple construction they carried to a high level, with great skill in stone carving and in the ceramic arts. We have noted how in



Fig. 13. An Egyptian stone figure representing a scribe and accountant who sold his services to the general public

the Old World trade and colonization developed out of the needs of the city and to this there were close parallels in 1492.

There is still a difference of opinion among scholars as to the degree of independent development in these two non-contemporary parallel ages, but no evidence has yet been produced to show that Egypt, Sumer, Babylon, or Troy sent traders and colonizers to the New World in 3000

B.C., or before. If laborers and craftsmen had settled here, they would have left behind pottery, metals, and other indestructible examples of their handiwork, but such have not been found in spite of the great amount of archaeological excavation carried on over a long period of time.

AGES OF KNOWLEDGE AND INDUSTRY

The remaining ages of man in the brief outline of inventions presented on page 715, belong to history rather than to anthropology, so we may pass over them hurriedly. What is meant by an Age of Knowledge is that a special interest developed in recording and organizing knowledge, along with the realization that improvements in ways of living could be made by the use of new knowledge, and that the rapidity in the discovery of new knowledge would result from the devising of better methods of research. The accumulation of wealth and power in the Age of Cities established sharp class distinctions in society which are still with us. The profession of the scribe and the calculator, the expert, was raised above crafts and unskilled labor to the status of a privileged class, probably because it was so intimately associated with the ruling wealthy class. The debased grade of slavery and that of peasants were fixed in folk customs, through the forced labor of captives and conscripted labor for the lowest class of citizenship. Special forms of education in training schools came into being for the training of scribes and other technical servants of the king, including the priestly class, which further widened the established class distinctions. So when greater store was put in the social value of knowl-

edge, and when the preservation of this knowledge was in the hands of the scribes, all learning and scholarship tended to find a place in the privileged class. So to this day certain occupations and professions are regarded as "upper-class."

The making of books, as would be expected, belongs to the Age of Knowledge, with reading closed to people of the middle and lower classes. No matter how brilliant such a boy or girl might be, he or she had little chance to learn reading or writing. The making of books had one drawback in that men began to learn from books rather than from nature, and assumed that what was printed must be final and correct. This, for a time, tended to inhibit the acquiring

of new knowledge and the re-examination of assumed knowledge.

The industrial age in Western Europe seems to have begun with the discovery of America and the circumnavigation of the earth, which opened up new markets for trade goods. New wealth now awaited the genius who could increase production and market his products. This stimulated the invention of machines and the application of water and steam power. Finished products in metals and textiles were the best sellers in foreign countries so these were the fields in which industrialization was rapid. We are still in this age, one in which progress seems to demand constant increase in markets, even if commerce must be forced by war.



Black Star from the Bettmann Archive

Fig. 14. Book production during the Middle Ages. Scriptorium of Jean Mielot, private secretary to Philip the Good, Duke of Burgundy. The writing of fine manuscripts took years. A monk sometimes spent a whole life time copying a single book

CHAPTER 28

CULTURAL ANTHROPOLOGY

ANTHROPOLOGY recognizes a phenomenon which is its chief concern. The usual name employed for this is culture. The term society is often used to mean about the same thing, though culture is a broader term. It is often said that biology is the science of life and in much the same way we hear that anthropology is the science of culture. Culture is what a community, or a natural group of people, does, a body of traditions, habits, beliefs, and customs in accordance with which the group or community lives from day to day. A large part of the literature of anthropology comprises descriptions of cultures, depicting the daily round of life in the community, village, or tribe, as the case may be. Each self-contained group or village has a culture, so to enumerate the communities in a given part of the world's surface is to designate the number of cultures to be found therein and the tribe or village name is generally used to designate it. For example, in southwestern United States, we speak of Zuni culture as the culture of the Indian community of Zuni. Sometimes a number of villages are considered as one people, as the Hopi in Arizona, whose villages are Walpi, Sichumovi, Mishongnovi, Shongopovi, Oraibi, Hano, and Shipaulovi. Strictly speaking, each of the Hopi villages has a culture, though the respective village cultures resemble each other closely.

To define the term culture is difficult—it is a phenomenon more readily sensed than described. We might say that culture is in the nature of a great

complex of what the individuals in a village or community know, believe, and practice. So we may leave the matter for the moment, at least until we have seen what makes up such cultures. A unit of culture is often spoken of as a trait. It so happens that in the case of the Hopi villages mentioned above, these villages fall into three groups standing upon three mesas or plateaus as follows:

East Mesa—Walpi, Sichumovi, Hano

Middle Mesa—Mishongnovi, Shongopovi, Shipaulovi

West Mesa—Oraibi

Those of the East Mesa make no baskets, those of the Middle Mesa make coil baskets only, while on the West Mesa wicker baskets only are made. Since basket making is a trait of culture, we note that the Hopi village cultures can be grouped as to whether they make baskets or not, and those that do fall into two groups according to their basket-making methods. Pottery seems to have been made in Walpi and Hano only, not in the other villages. On the other hand, the men did the weaving in all the villages. Thus some traits are common to the cultures of all the villages, others variously distributed among them.

These illustrations enable one to sense what is meant by traits of culture, and to understand that cultures are distinguished, the one from the other, by the absence or presence of these specific traits. To make an inventory of the traits in any culture is something of a job in itself, even a

simple, primitive culture will comprise several thousand items, most of which can be recognized as traits of culture. Every community, or village, has a culture composed of about the same number of such traits, though the range will be upward rather than downward. Two cultures will be considered identical when approximately all the traits are identical; similarly, the number of traits in which they differ will determine the degree of difference between the two.

It appears, then, that cultures are indefinite wholes, or complexes, the traits, or components of which can be listed, evaluated, and counted, and that to compare and to classify cultures, one must take note of such an enumeration of traits or components. Returning to the Hopi villages again, we should soon discover that a very

large number of the traits listed for the Hopi villages will approximate identity, so that for practical purposes we may consider all of them to have the same type or form of culture. On the other hand, if we choose an Eskimo village in Alaska, the differences between this and a Hopi village will be so many and the parallels in traits so few, that it will be safe to infer that Eskimo villages will be of a different kind or type. It follows that the first job in studying the culture of a village is to make a list of the culture traits they practice. To do this well the unfamiliar traits must be described at length. This accounts for our meeting with large memoirs on the Hopi, Zuni, Alaskan Eskimo, etc., when we look over a bibliography of anthropology for these cultures have been studied extensively.



Fig. 1. Modern pueblo village of Walpi, Arizona, showing terraced sheep corrals. It stands seven hundred feet above the plain

CULTURE COMPLEXES

Having in mind the idea of a culture trait, we must look deeper into the place of the trait in culture. It is not a clear-cut unit in itself but a kind of association or chain of culture events which in sequence reach an end important in the culture concerned. We can illustrate this by the use of wild rice as a food by certain American Indian tribes in Wisconsin. The plant is a kind of grass, like oats or other grain producing grasses, which grows in shallow water. We are familiar with wild rice grains as we purchase them for cooking, but

there is a rather long sequence of techniques antecedent to the appearance of the package of rice grains upon the grocer's shelves.

These techniques are traits in the culture of the Indian tribes producing the grain for distribution in the market or consumption around their own campfires. Thus, at the outset, the swamps or lake margins are divided among the prospective harvesting families, represented by the adult women. Several species of birds are fond of wild rice when ripe, but their method of feeding upon the grain is highly wasteful because when they perch upon the standing stalks to



American Museum of Natural History

Fig. 2. Eastern Woodland Indian life, a general pattern of culture, painted by A. A. Jansson



Wisconsin Conservation Department

Fig. 3. Indians of Wisconsin gathering wild rice. The production and use of rice constitute a culture-complex

peck at the grain, most of it shatters out and falls into the water and being heavy sinks to the bottom. So just before the rice ripens the Indian women push their canoes in among the thick, standing stalks and tie the heads of twenty or more stalks into bunches. For this they use twine of their own making, from the inner bark of the basswood tree.

When the grain is thoroughly ripe, the tied bunches of heads are gathered for hulling. To remove the hulls the heads are beaten in mortars by men and women, after first being heated or parched. Next the chaff must be removed by winnowing in the wind. If some hulls still adhere

to the grains, the rice is poured into a barrel-like vessel and tramped by a man wearing moccasins. When the last of the hulls have been winnowed away, the rice is put into bags for future use, or for marketing. There are a number of social practices associated with this series of technical processes in the production of wild rice, the whole forming a kind of complex of related procedures.

This illustration may make clear to you what is meant when anthropological writers speak of a wild-rice trait-complex, or simply of a wild-rice complex. Other examples of complexes could be cited, as the cultivation of maize, the use of the horse, etc.

DIFFUSION

A culture trait-complex can spread from one culture to another by a process of borrowing. The first appearance, or origin, of a culture trait is due to invention, after which it can be borrowed by neighboring communities or cultures, and thus, by successive borrowings, spread or diffuse over a large geographical area, or even over the entire world. Theoretically, the same invention can be made independently, many times by tribes widely separated, but often the area of diffusion is such as to suggest that but a single invention was made, and that other cultures borrowed it, thus diffusing it over a large area. Some of the culture complexes believed to have a single origin are pottery, maize, domestication of the horse, smelting of iron, the bow, the phonetic alphabet, the wheeled vehicle, and the stone arch. No one denies the possibility of independent invention in connection with these and other widely diffused complexes, but so far the evidence for such independent origins is not considered conclusive. On the other hand, many of the leading anthropologists have considered the following inventions as having been made in both the New and Old Worlds independently: bronze, *cire-perdue* casting, bark cloth, beam scale, domestication of bees, blow gun, paper, writing, steel-yard scale, drum signaling, fermentation of intoxicants, and boiled water for wounds. The chief reason for believing these independent inventions is that they appear in the New World at different times than in the Old, and in many cases take original forms. For example, the form of writing in ancient America is of relatively re-

cent origin, but is quite original when compared with Old World forms of writing. If it had been diffused from the Old World, it should show close resemblances to at least one Old World mode of writing. Yet, since the evidence is largely inferential and not direct, such examples are open to controversy. We can be sure, however, about many inventions made in the New World but not known to the Old World before 1492, thus proving in a way that many inventions were made only once. But this is of no great importance, since no one seems to deny the possibility of independent invention, and the evidence for ready diffusion shows that useful inventions can spread over large areas, thus making them parts of many cultures.

The scientific importance of the diffusion concept is that it supplies the answer to most questions of culture origin. When seeking for the origin of a culture complex, like the domestication of the horse, for instance, we trace the diffusion of the complex over the world. Many Indian tribes of our western plains, when first discovered by white men, were using horses, but by historical data we are able to trace their horses to the Spanish settlements in Mexico, whence the horse was brought from Spain in 1521. Horses escaped from Mexico and were stolen by the Indians at every opportunity, first by the Indians living next to the settlements, and then by neighboring tribes, until they passed on to far-distant tribes. Thus, by diffusion, the horse finally reached the grass-covered plains of Canada before that part of the country was explored. In the Old World the domestication of the horse seems to have originated in the steppe country of western Asia, about 5000 B.C., diffusing first to the

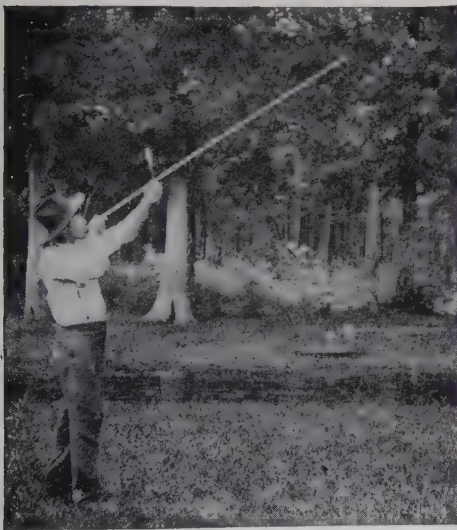
ancient civilizations, next to Egypt, to southern Europe, to North Africa, and to China. In fact, wherever the horse could live, the culture complex found its way, ultimately reaching England, and finally Iceland, about 1000 B.C. Along with the horse was diffused the chariot, bridles, saddles, harness, armor, etc., as well as methods of riding and of using the horse in war. In this way historians and anthropologists have followed the diffusion of the horse complex as it spread over the world. When we find Indians in Canada using saddles of their own make, resembling those of the Moors in Spain and Africa, we are sure that the explanation is diffusion, because the Spanish colonists brought them to the New World.

At this point note should be made that the origin of the horse complex in any country and time after its initial invention is best designated as a



Rochester Museum

Fig. 4. A Seneca woman washing maize after it has been hulled by boiling the grains in wood ashes or lye. This process was taken over by the white colonists



Museum of the American Indian

Fig. 5. Louisiana Indian demonstrating the use of a blow gun. This is an old pre-Columbian weapon which probably diffused from South America

historical phenomenon. Thus the explanation as to the presence of the horse in Egypt and in the New World, for example, is a historical one. This is different from the concept of biological evolution by which we explain the origin of living man as the result of a long chain of biological reproductive processes. What is really meant is that, whereas in biological evolution there is a continuous passing on of germ plasm from each successive species of living form to the next, in the origin and diffusion of a culture complex, we begin each time with an invention, which may be modified by subsequent inventions, but which has an origin independent of any other invention. New cultures are formed by discarding old inven-

tions and making new ones. Many scholars assume that the direction and end of biological evolution is fixed and predetermined by biological laws and conditions, whereas in the historical development of culture complexes there are no limits. Naturally this is a theoretical, philosophical question about which there may be sharp differences of opinion, but the historical method of approach is obviously the proper procedure in dealing with cultures. The study of culture and the studies of the historian are thus seen to rest upon the same foundation—each is interested in learning where and when complexes originated and whence they spread or diffused.

All communities seem to have an itch to borrow new inventions. If a community adopts a new form of hat, a new kind of tool, or a new food, all its neighbors soon want it too. This is spontaneous and comes naturally. A community, as the name implies, is a group of people who tend to do things in the same way, so that once the new object or the new way is seen among their neighbors, they, too, want to be regular, or in style, as we say. This same tendency appears even in such fundamental affairs as religion and marriage. If a new form of religious belief appears in a neighboring community and begins to stand out conspicuously, to be sincerely practiced by its devotees, sooner or later it finds sympathetic supporters among other communities. If finally it becomes the leading religion of a culture group, and this group is otherwise powerful and successful, neighboring groups are moved more and more toward its adoption. There is usually a good deal of resistance to such changes, especially in case of differences in the marriage systems of the world, but

no culture complex has proven invulnerable to the spontaneous spread of others by diffusion. The same can be said for communism, totalitarian states, Fascist systems, etc. Once one of these is in vigorous operation, it begins to impress other peoples and ultimately leads some of them to adopt the same social forms.

CULTURE GROWS BY ACCUMULATION

Culture is passed along from individual to individual. As a rule the individual is born into the culture of his relatives and becomes conditioned to it. Unless he goes to live in another group with a wholly different culture, he follows strictly the culture pattern of his native group. He had nothing to do with the formation of the culture, nor does he have a chance to choose his culture. He is too immature for that and wholly dependent upon his parents for a chance to survive. When he has grown up and is able to support himself, he could go to live in another culture but would find it difficult to adjust himself to it. A new language would probably be necessary, new habits of thought, possibly new ideas of morality, all of which would take years to achieve. Of course, if he were moved as an infant or a very young child, the adjustment would be easier and thorough. During the many Indian wars in the United States, small white children were occasionally carried off and brought up as Indians, so that when discovered later, they knew little English and preferred to remain with their Indian friends. White people were usually shocked to find that these captives refused to be rescued.

An interesting example is that of Frances Slocum, captured in Wyom-

ing Valley, Pennsylvania, when five years old, and adopted by a Miami Indian family in Indiana, along the upper Wabash River. Shortly before her death, she was located and identified by her surviving white relatives about whom she could remember next to nothing. In the meantime, she had married and was a grandmother. She did not know enough English to talk with her relatives in that language and so was not overjoyed to meet them or to learn of her origin. She declined to leave the Indians and take up residence among strangers—to live under a new culture. In technical language, she was completely conditioned to the Miami Indian culture, and at her advanced age could not have been happy living among white people. It would be correct to say that her brothers and sisters, who escaped capture, were conditioned to the white culture of Pennsylvania, whereas she was conditioned to the Indian culture of the Miami tribe. It is the process of conditioning which preserves cultures, handing them on from one generation to the next. This is what is meant when cultures are said to have continuity.

In the preceding section we spoke of diffusion, or the spread of culture from one group to another, but we now see that it also enriches cultures by adding new complexes. In other words, cultures tend to be accumulative, and if communities are not too wasteful of their culture inheritance, they may eventually come to possess a culture rich in complexes. In a country like our own, one lives under a form of culture possessing so many, many complexes that the enumeration of them becomes bewildering. This came about by accumulation, by

retaining more culture complexes than were discarded. A long time ago some group of manlike apes discovered or invented speech, and since that time every human culture group has possessed a language. The con-

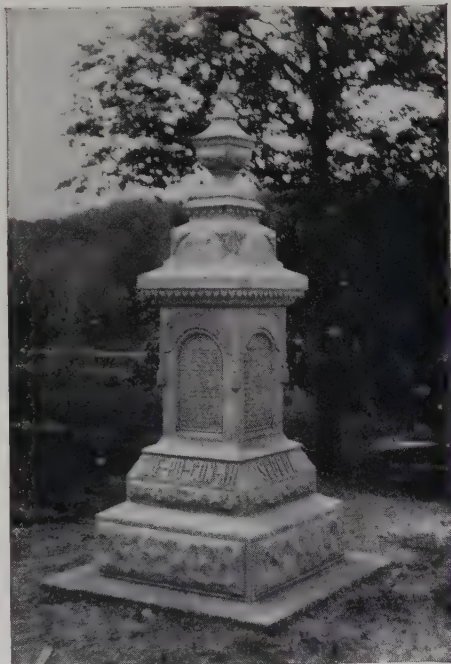


Fig. 6. Monument to Frances Slocum and her Indian husband. She was a white child, captured by Indians, who lived the life of an Indian. The monument is near Peru, Indiana

trol of fire was discovered, stone tools invented, burial of the dead invented, forms of society devised, etc., which have persisted until the present. Weaving and the twisting of string is another striking example. It is conceivable that in the far-distant future, cultures will contain a much greater number of complexes than now.

Naturally, not all culture complexes survive. Yet the important and use-

ful complexes are slow to disappear. One frequently reads in popular literature about the "lost arts," but few of them are really lost, since a study of the artifacts in question usually reveals the processes necessary to their production. A great deal of experience with animals, plants, and minerals has been handed on from culture to culture—what plants are poisonous, what reptiles venomous, what plants have narcotic properties, etc. Quinine and coca, two of the most useful medical plants, were discovered by the Indians of South America. These Indians even discovered that the seaweed, kelp, was a cure for goiter, though they were not aware of the iodine content of kelp as the specific curative agent.

Among the narcotics of prehistoric origin are opium, datura, nicotine, and hemp. All these were discovered by trial and error before science had devised ways of analyzing and testing drugs. We should not overlook that a good deal of misinformation is incorporated into culture, passing

under the name of folk medicine, magic, and superstitions. Although based upon erroneous assumptions, these are nevertheless a part of the cultures in which they are perpetuated. Science is gradually leading us to eliminate many of these false practices from modern cultures. Many harmless parts of culture survive long after their original functions have ceased. Such traits and complexes are called *survivals*.

The English anthropologist, Tylor, originated the term "survival" as the name for a method of explaining the origins of meaningless traits in a culture. For example, the early railway carriages were like stage coaches and the first automobiles looked like buggies. There are many examples of survivals in art and in decorative designs. In ceremonies survivals often result in a kind of symbolism, as a mock fight at a wedding may symbolize a former practice of taking a wife by capture in war. One difficulty in using survival as a method of explaining the origin of culture complexes is that unless actual historic information is present, one cannot prove that what is now observed is a survival. As an instance of this, a theory has been advanced that all games were once serious attempts at magic, but since the actual history of most games is wanting, no one can be sure about it. At one time in the development of anthropology a great deal of attention was paid to the concept of survival, but it is now considered of little value.

As stated at the outset, the culture of a given group at a specified time is the result of accumulation, a survival of the knowledge and experience pertaining to a large number of extinct cultures. This is possible not



Courtesy of the B. and O. R.R.

Fig. 7. An example of survival in culture. The first railway carriages were patterned after stage coaches

because cultures are immortal, for they do die, but because of diffusion, which spreads the various complexes of culture to neighboring groups. This is the way in which cultures have been enriched, by conserving their capital and consolidating their gains. It is one great advantage human society has over animal and insect ways of living.

CHANGE IN CULTURES

The most characteristic thing about cultures is that they are always changing. Not only are new complexes being borrowed from time to time, but old complexes change by varying their constituent traits. In our own culture it was once the mode for each family to do its own spinning and weaving, whereas now, cloth is purchased in the market. Once each family baked its own bread, now bread is bought in a shop or is factory-made. Such series of changes have come about in a short time. Nor is any complex in our culture immune to such changes. Some people speak of this as progress, but in science it seems best to speak of it as change, because whether it is for the better or the worse, is a matter of hope rather than certainty. Cultures pass through a kind of cycle in that they grow rapidly and later decline. When they are declining, they are changing, just as when they are rising. The processes are much the same in either case, and since we are here interested only in what they do, a declining culture is as fit a subject for study as a rising one.

The important point is that change is the normal procedure in a culture. It is often assumed that most primitive cultures do not change but go on from age to age in the same way.



American Museum of Natural History

Fig. 8. Menominee Indians in mixed aboriginal and European costume

This is in part an exaggeration, because when close note is taken of what goes on in such a primitive culture, changes are in evidence. So long as a given food plant or animal is available, the methods of using it as a food are likely to continue, but the supply is subject to fluctuations, due to slight changes in climate or the inroads of plant and animal diseases, not to overlook the fact that man himself may tend to exhaust the natural supply. Should a new food become accessible, the food habits of the group might change and so bring about a corresponding change in the culture. Groups are always tempted to borrow culture complexes from their neighbors. If they should be in contact with European culture, the



Museum of the American Indian

Fig. 9. A Navaho Indian man knitting, an art copied from white people

changes are certain to be rapid and often extremely revolutionary.

Our attention may be called to some of the Indian villages in New Mexico, whose costumes, houses, and ceremonies look strange to us, as examples of culture without change, and yet white people who live near by are aware that changes are under way. Most of the men now wear ready-made clothing of white manufacture, use plows, reapers, wagons, and threshing machines. Glass windows and modern furniture may be seen in their houses. Some use sewing machines, not to mention metal tools, glass and porcelain kitchenware, etc. Sugar, salt, tea, coffee, and flour are purchased regularly from a trader. Even canned goods are consumed in quantity. There are changes in other parts of the culture of these Indian villages. Most of the women in these villages make pottery for sale to visitors, but the styles in these pottery



Smithsonian Institute

Fig. 10. Trail leading to the Indian village of Acoma, New Mexico, one of the oldest surviving villages

objects change from year to year, encouraged by better markets for the styles which happen to be popular. Some of the men make toy drums, carve quaint wooden figures, make small bows and arrows, and the like. Such are after all a part of their culture. Even ceremonies change, some cease altogether and new ones spring up or, more often, are borrowed from other Indians.

A few years ago an original form of painting on white cardboard was invented by an Indian, a new art which was so attractive and intriguing that it quickly diffused through the villages. A great many of these paintings are sold every year to white visitors to New Mexico. Indian children attend the government schools where many learn English sufficiently well to carry on a conversation about ordinary subjects. In this way they come to know more and more about the ways of white living, all of which promises that more and more culture traits will be borrowed from the white culture around them.

Something like this goes on in every culture, no matter how primitive. Change may occur faster in some than in others, but none escapes it. For change of some kind, in varying order and speeds, is the way of cultures. All cultures have their peculiarities; sometimes they will be ultra-conservative about a few complexes, holding on to them firmly, whereas others will slip into disuse and be replaced by newly borrowed culture complexes. There is no safe way to predict what cultures will do, so our studies must be historical rather than predictive, we are sure of our ground only where we tell what actually has happened and sometimes even here the evidence is not complete.

DIFFUSION AREAS

We have noted the large part diffusion plays in spreading trait complexes from one culture to another, but when the geographical distribution of complexes is regarded, areas of diffusion begin to appear. Such areas are sometimes called culture areas because the cultures of the several tribes within the area have many complexes in common. For example, nine culture areas are usually assumed for the aboriginal United States and Canada, as shown on the map on page 744 (Fig. 11). We have used the Plains Indian cultures as illustrations in the preceding discussions. They were similar in many things, the horse complex, use of the buffalo, tepees, costume, art, war customs, ceremonies, etc. In the Southwest, we cited the Hopi, Zuni, and other villages, whose cultures are similar in many such complexes, as dependence upon maize, weaving, pottery making, kiva ceremonies, etc.

A number of complexes are peculiar to each one of the nine culture areas, for example, the horse culture of the Plains area. In no other area was the horse so intimately fitted into the culture of the area. Not only did the horse complex diffuse over the whole area, but its diffusion tended to stop at the edges of the area, so that when we speak of horse Indians we know at once what Indians are meant, and that associated with them are the buffalo, beaded costumes, tepees, buffalo robes, feather headdresses, war, etc. When we pass to the other areas these traits are conspicuously absent.

Once you become familiar with collections in a museum, you can easily place most of the objects you see according to the culture areas from



Fig. 11. Map showing the location of primitive culture areas in North America. Note that the United States and Canada have nine separate areas and Mexico has one

which they come. It will be far more difficult to decide from what particular tribal culture the objects came.

We are now ready to consider how culture complexes came to "gang-

up" in such areas rather than spread each in its own way and at random. A clear-cut answer cannot be given, but it seems that the complexes in such an area are somehow associated

or integrated one into the other so that they follow each other in diffusion. One theory is that as a group of complexes or as a way of life, they are peculiarly adjusted to the country and its animal and plant life, which is to say that taken together the observed culture complexes present a satisfactory and successful way of living. One test of a culture is its ability to survive and maintain its numbers. From the coming of the horse to the settling of white men in the Plains area, the tribes living therein were able to maintain themselves and to live in reasonable health and security. The proper answer may be just that. This form of culture worked at the time, apparently better than the preceding culture and once adopted by a few tribes spread to the others. The reason the horse culture spread no further may well be that it was economically impractical in the adjoining geographical areas. However, this falls under the head of controversial questions, which most scholars answer according to their prejudices. Later, we shall have a closer look at this problem.

We may now venture a definition of culture area, it is a region of the earth's surface with general climatic and geographical homogeneity in which a number of primitive, similar tribal cultures have their habitats. Recalling that we previously asserted that no cultures are static but that all change with time, we should add that these North American culture areas, as defined on the map, are approximately as of 1650-1850. Archaeology indicates somewhat different prehistoric areas and different types of culture complexes diffused in the respective areas. The map, therefore, represents a cross section of diffusion

areas in 1650-1850; had white people remained in Europe for the next five hundred or more years, new diffusion areas could have evolved. When archaeology has advanced in its reconstruction of the past we shall be able to say in how far the geographical boundaries to diffusion areas remain constant. One impression we now have is that culture differences among white people exist between these same geographical areas as noted for Indians. The reader can test this out in his own thinking if he has traveled enough to know what life is like in these same regions. For example, compare white rural life on the plains with rural life in New Jersey. If white cultures are different, if there is a Plains region, a California region, etc., in white culture, then a strong claim can be made for the influence of geography in the formation of diffusion areas.

But whatever may be the causes that give us diffusion or culture areas, they are useful as a means of classification. It is much more economical in time and labor to remember nine culture types in North America than to keep in mind a list of several hundred separate individual cultures. So our best disposition of the question is to say that there are diffusion or culture areas, whether or not we can explain their existence satisfactorily.

GEOGRAPHICAL DISTRIBUTION

Anthropology is an earth science. By this is meant that the facts of anthropology have geography, that is, they vary from place to place. Chemistry, electricity, and physics are supposed to follow the same laws no matter in what part of the world the observations are made, but this is not necessarily true in anthropology. We

must know about anthropological facts where and when they occurred. Sometimes anthropology proceeds upon the assumption that its facts are three dimensional, which means that they are located on the surface of the earth, which has length and breadth, and that they have a place in time also, which may be expressed as depth, the whole forming a kind of three-dimensional projection. Here, however, we are concerned with horizontal distribution without regard to time. The chief reason why anthropology considers geographical distribution so important is that there is an underlying theory by which geographical distribution is interpreted.

The German school of human geography, as it is called, led by Ratzel, was disposed to look upon the spread of culture over the world as its chief problem. As Ratzel conceived the geographical distribution, it was the expansion of cultures in the central Old World that spread cultures everywhere and which eventually formed civilization. His idea was that once we know how culture complexes are spread over the earth, we will be in a position to understand by what steps they came to be that way. Instability of habitat, or migration, is regarded as universal, for even under primitive conditions there were adventurers who, like Daniel Boone, Marco Polo, and Christopher Columbus, were ready to lead their restless countrymen into new regions, crowding out peoples already there and introducing new culture complexes. That this process is as old as man was the belief of Ratzel. Time has altered the views of Ratzel, but his main idea still stands. He did not recognize that culture complexes may diffuse over large parts of the earth

without militant migration, that peaceful penetration by new culture complexes is in constant movement.

Colonization is the less peaceful way of spreading people and cultures. We are inclined to look upon colonization as something distinctly modern, whereas it is really an old, old method of expansion and diffusion. Rome established colonies in western Europe, in England, and parts of Africa. Before that, Greece had colonies around the Mediterranean Sea and in Asia, Egypt preceded them, and so on back into Neolithic time. We have historical documents to prove this; that is historical evidence. However, knowledge of these matters can be enriched by archaeological discoveries of the ruins of Roman colonies in Europe and England for which there were no satisfactory written records.

In the New World there were similar colonization movements under way when Europeans began to explore the country. For example, the Aztecs in Mezico were expanding outward from Mexico City establishing colonies here and there. Tribes from the Woodland area east of the Mississippi River formed settlements in the Plains area, becoming non-agricultural horse Indians. The Cheyenne did this before horses became common. Some Ojibway and Cree bands settled in the plains of Canada after 1800, soon becoming thorough-going horse and buffalo hunters. Since most of the parent bodies still lived in the forested country of the east, these settlers in the Plains were called Plains Cree and Plains Ojibway. We assume that long before the acquisition of the horse the Blackfoot and Arapaho tribes came out of the forests of the east and settled in the plains, but they seem to have lost

whatever traditions of migration they once possessed. Our reason for assuming this is that their speech belongs to the Algonquin family of the Woodlands and in particular resembles that of the Cree and Ojibway.

These are not unique examples, for in every culture area of the United States and Canada we find such colonizing tribes beyond the borders of their respective areas. We can discover such prehistoric movements by taking note of the geographical distribution of the language families to which the intruders belong, and sometimes by the presence and absence of certain culture complexes. This is what we had in mind when we stated that certain theoretical concepts of

the relation of geography to the facts of distribution made it important to gather information as to the geographical distribution of culture complexes. Now we see that the distribution reveals diffusion areas, migrations and the environmental relations of culture complexes.

ENVIRONMENT

In both biology and anthropology the environment is considered one of the important influences shaping the ways of life. In the first place animal and plant life is of great variety because each species is adapted or adjusted to living in a specific environment. Anthropologists consider that the forms of culture are adaptations

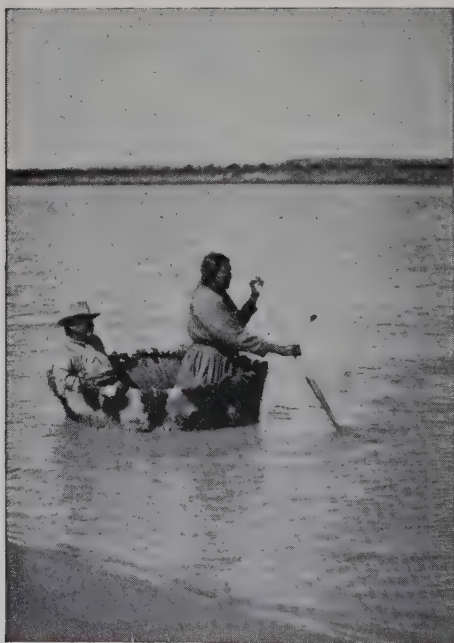


Robert E. Coates

Fig. 12. Modern pile dwellings in New Guinea

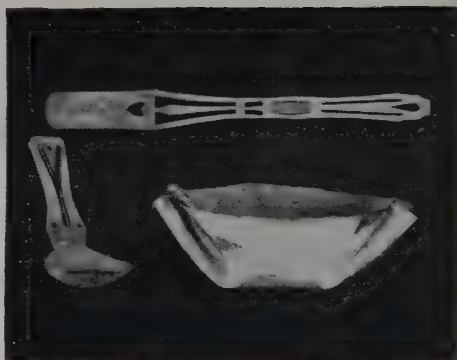
to living in specific places and times. They assume that the environment changes too, and that the form of culture found in a given locality is for the time being the line of least resistance in adaptation to the environment. The diffusion area is explained as that part of the earth in which the culture complexes diffused therein are successful and practical solutions to the art of living in such an environment.

To put the principle into concrete terms, a culture complex can diffuse only so long as environmental conditions are such that it can operate. In case of economic matters the relation is clear. Thus a boat-using complex will not diffuse into an area



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Fig. 13. A tub-like boat covered with cow skin used by the Indians of North Dakota. This is the only kind of boat used in the semi-arid plains of the United States



American Museum of Natural History

Fig. 14. Utensils of the Woodland Indians used in making maple sugar: wooden paddle for stirring boiling sap; wooden ladle; birch bark vessel for collecting the sap. This industry was limited to the habitat of the sugar maple tree and did not spread beyond

where there are few navigable water courses or one in which the dry climate renders most of the stream beds dry during a large part of the year. For example, in southwestern United States most of the streams are dry except during heavy rainfall. Lakes of suitable size are non-existent. Even such rivers as the Colorado and the Rio Grande are either too swift or too shallow to encourage the use of canoes. A part of the Plains country is moderately dry and while there are many streams rising in the Rocky Mountains and finding their way southeastward toward the Missouri and the Mississippi, it was easier to traverse the open grassland than to follow the streams up and down. Besides, the buffalo, the chief food animal, roamed north and south, in the main at right angles to the direction of flow in the rivers. So the ease of travel on land, the adaptability of dog traction to environmental conditions, and the habits of the buffalo, all presented a complex of conditions unfavorable to the

use of canoes or boats. The streams and rivers presented obstructions to travel only when too deep to be forded. This explains why the only boat used was a tub-shaped affair, made of poles and skins, used for crossing rivers too deep to ford. There was use for a technique of crossing large deep streams, so the use of the quickly made circular skin boat diffused over the parts of the Plains Culture area where it could be used.

Again, the horse complex diffused over the Plains area because there was abundant natural food for the horse all the year round, and it was easy to travel without clearing the land and constructing roads. The horse complex was peculiarly adapted to the environment to be met with in this region, not merely for transportation, but for hunting and in war, all of which makes it easy to understand how it was that the use of the horse spread quickly throughout the whole grassland area.

Another principle aiding in our understanding is that whenever one of the cultures in a culture area invents a new and more effective adaptation to some factor in the environment, that invention or culture complex will quickly spread to the whole of the area. We once spoke of the wild rice complex and it will be found that the exploiting complex associated with this wild grain was diffused to the localities where wild rice grew in sufficient quantities to be an important source of food. Maple sugar is another example, since its production diffused over the area in which the sugar maple grew abundantly.

On the other hand, there are some complexes in cultures which seem to be independent of the environment, as marriage, magic, religion, games,

and art. In the first place the ways of producing food observed in a culture seldom exhaust the possibilities of the environment. The same is true of materials used in the production of clothing and housing. Culture is an adaptation to a part of the environment, not the only solution to the problem of how to live in it, but when we turn to marriage, games, or religion, it often appears that certain forms of these are better adapted to the material economic ways of living. Among a hunting, warlike people there are usually more adult women than men, hence some form of plural marriage is suitable to such a culture environment. Again, if hunting and wars become too exacting, some form of female infanticide may diffuse over the area concerned. For example, there is the Eskimo area where it is difficult to balance the sexes and to survive the long winters with their meager food supply unless there are many male hunters. So it is not difficult to discover adaptation of even such complexes as marriage to other important complexes within a culture area. Once steps were taken to adapt marriage, for instance, to the local way of life, this new modified complex would soon diffuse wherever the total culture situation was the same.

Thus we see that one reason for a culture area is that it presents at the time being certain natural resources easily exploited by the primitive communities settling within its boundaries, but that when the settlers begin to exploit these new resources they find it advisable to change or modify other complexes in their cultures, which naturally diffuse over the entire area possessing these resources. To state the situation another way, people who live in a dry

country will possess cultures different from those who live in a wet country, those living in cold countries will differ from those living in warm countries, etc. One necessary condition to such variations in culture is a varying environment.

CULTURE PATTERNS

Anthropologists have another useful term, the culture pattern. This is used in several ways, all comparable. For example, the parts of complexes may resemble each other, or have common elements. This is the case with the Indians of the Eastern Woodland culture area who boil maize, acorns, chestnuts, fiber of plants, and animal skins in wood ashes as a step in the various culture complexes involved in the prepara-



Rochester Museum

Fig. 15. Model of an Iroquois Indian storehouse for maize



Museum of the American Indian

Fig. 16. A camp of Plains Indians showing the use of tipis

tion of these materials for use. Wood ashes produce lye which may be useful with some of these materials but apparently not with others. Anthropologists would call this *pattern phenomena*. Acorns are used as food in the California area, too, though there they are not boiled in ashes to extract the poisonous tannin, but the pulverized acorn meal is merely "leached" in hot water. In other areas, skins are dressed without boiling them in ashes. This is further proof that the pattern of boiling in wood ashes has been extended to many processes in the Eastern Woodland area.

Again, the unique culture complexes in a culture or in an area, may be taken as parts of a pattern. For instance, the complexes buffalo, horse, tepee, sun dance, coup, and soldier societies are said to define a culture pattern we call the Plains Indian pattern, because the various tribes in that area had cultures the patterns of which coincided in these unique complexes as well as in others. Ar-

chaeologists use the term basic pattern as a term of general classification in dealing with prehistoric cultures. Thus they use the term Upper-Mississippian as a subpattern under the basic pattern Woodland culture covering most of the Mississippi Valley. In a similar vein, we speak of a California pattern, a Southwest pattern, an Eskimo pattern, etc., when discussing the culture of living Indians.

Mythologies and rituals reveal tribal and area patterns. For instance, the Pawnee Indians possess a number of rituals each associated with a bundle of objects wrapped in skin and opened only when the ritual is performed in the required manner. An inspection of these rituals shows that they are composed according to a master pattern. The Blackfoot also has a large number of rituals with bundles; they, too, have a master pattern. There are a number of points in common between the rituals of these two tribes of Plains Indians. Similar rituals with bundles are found among some other Plains tribes. Thus the comparative study of these bundle-ritual patterns tells us something of how these rituals and bundles originated, and that when a specific pattern was once established in the culture of a tribe, new rituals were composed after the same pattern. Diffusion carried some of these patterns to other tribes, where they usually came into conflict with other ritual patterns, with resultant substitutions and eliminations. Yet, if the dominant points in the borrowed pattern were retained, a comparative study of rituals will usually reveal them and suggest the source from which the patterns came. In the case of the Pawnee pattern the concept

of Mother corn is used in such a way as to indicate that the main outline of the pattern was borrowed from the Pueblo Indians of the Southwest.

In mythology patterns are often followed. The Blackfoot Indians use a tale, or story, to account for the



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Fig. 17. Painted buffalo robe used by the Plains Indians

origin of each ritual, leading to a pattern so well fixed, that in tales obviously borrowed from other tribes who do not use tales in this way, the Blackfoot feel it necessary to add a kind of postscript telling the listener that it was the hero of this tale who originated a well-known ritual or who became one of the prominent stars in the heavens. This use of pattern is little different from style, except that the pattern may be carried over into many different kinds of complexes, material as well as social. We see pattern phenomena at its best when a borrowed complex happens to be incompatible with an existing

pattern. Such a collision may lead to social conflict and occasionally to war.

ACCULTURATION

In recent years anthropologists have become interested in observing how native peoples situated like the American Indians change their cultures by adopting the customs of white people. The name given this procedure is acculturation.

The chief reason for making this a subject of research is that it is a part of the movement to modernize the world. It is also a practical social problem, since governments must formulate policies for promulgating

and enforcing laws to regulate the processes involved. Almost everywhere the original natives surviving their conquest by white governments are residing upon reservations dependent upon these respective governments for support and protection. Under these conditions the native cultures are abandoning their old customs and taking up new ones borrowed from white people. Many anthropologists believe that the study of what goes on in the culture group while these changes are taking place will be typical of all culture changes.

All of these studies in acculturation are new and still in the pioneer stage, so that an attempt to summarize



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Fig. 18. Painting of a Plains Indian encampment of about 1870

them must be tentative. Among these tentative conclusions are suggestions that native peoples make greater progress under native leadership than when white men lead. The results are even more marked when the community as a whole responds to a situation. For example, in New Zealand the government decided to set up dairy centers for the various communities of Maoris, as the native peoples are called, expecting that the natives themselves would eventually operate them. Most of these enterprises failed because the Maoris did not take sufficient interest in supporting them but when a study of the few successful ones was made, it was observed that the leaders of the successful groups were Maoris also. Such leaders were able to call forth the spontaneous interest of the group.

Again, in the case of the Menominee Indians in Wisconsin, it was observed that they would work long hours for a low return picking ferns for the florist market and wild berries when the season came, rather than in other forms of labor at better wages. Here not only were the leaders native but the whole tribe, old and young, regardless of sex, participated. The emotional satisfaction the group derived from this joint enterprise stood in sharp contrast to that experienced by the group when the men were called out to work on jobs like repairing roads, or cutting timber. Many other examples could be cited to show that primitive groups possess patterns of operating as wholes, or for making the production of goods a social procedure, in which emotional satisfaction is the chief compensation.

Some patterns in the old native culture are sure to come into conflict



Museum of the American Indian

Fig. 19. Zuni Indians of New Mexico winnowing beans

with the new. Many Indian tribes in the United States and Canada burned down the house after a death. Their original economic system was adjusted to this behavior and so the culture was not disturbed by the procedure. From a sanitary standpoint there is much to be said in defense of the practice. However, when the Indians moved to reservations and the Government built log houses for them, the custom was uneconomical. At first the Indians were advised to use the cabin as a stable or a storage place. Later, as trees became scarce, they were persuaded to pull down the log cabin in which there was a death, and rebuild it upon another site, thus making it a new house. Eventually the final step was taken, the custom was abandoned completely.

Patterns controlling sex differences in occupations often brought on serious conflicts. Among many Indian tribes agriculture was the work of

women. When reservations were established, the Government tried to teach the Indians to farm, but the men revolted at the idea as degrading them. They could not take up farming and retain their self-respect. Had the Government been wise enough to recognize this at the start, by encouraging the Indian women to farm, the men could have been won over gradually. In several instances Indian women took kindly to raising cattle and sheep, even in the face of strong governmental opposition. Perhaps the opposition of the Government was unwise in not encouraging the women to raise livestock. Yet, the opposition of the white people to encourage Indian women to take up such work is natural; they wanted the Indians to become "civilized" and so could not tolerate the spectacle of women working in the fields and tending cattle and herding sheep, because such behavior was not considered proper for women and so threatened to disrupt orderly social relations.

In these acculturation studies attention is given to the psychological effects of the difficulties the natives experience in adjusting themselves to such changes in culture as we have cited above. Many individuals in the tribe become depressed and discouraged because they are frustrated by the conflicts between the new culture and the old. Their native religion and philosophy of life is their last resort, but this gives them little ground for hope. Their own failures tend to convince them that their future is hopeless and that their gods have deserted them. When a people once reach such a state of mind, they are well started on the way to extinction. The government in charge must

set in motion a program of wise, patient rehabilitation if the native people concerned are to find a secure place in the culture of the white race. It is a perplexing problem, one which calls for patient study before a wise policy can be pursued. One of the most important services anthropology can render to society is the understanding and insight into the nature of culture and human behavior which will result from studies in acculturation.

ANIMISM

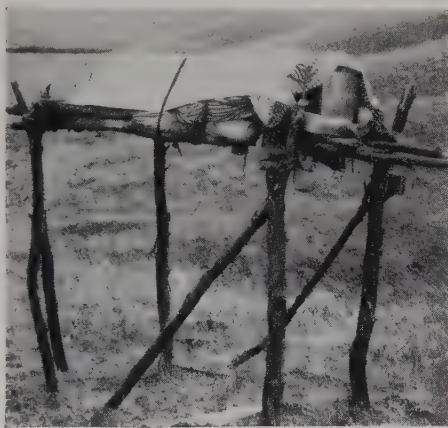
The English anthropologist, Tylor, whom we mentioned in connection with survivals, proposed a theory of animism, or the science of souls. He was impressed by the universal belief of all kinds of people, primitive and civilized that the individual is of two parts, a material body and an immaterial spirit or soul. He assumed that since all primitive people had such a belief there must be some natural cause for it. First he saw good reason to assume that the minds of primitive and civilized peoples worked in the same fundamental ways and so looked about for situations in life to which no other interpretation was possible. He thought he found this in sleep, dreams, visions, trances, and death. When the sleeper narrated his dreams to his fellows who knew that he had not been away, but that his inert body was in its accustomed place, they saw no way to explain the occurrence except to assume that an invisible part of the sleeper had power to leave his body and travel around unseen. The similarity between sleep, trances, and death could be easily explained in the same way by assuming that the invisible part of the individual was immortal and lived forever. See-

ing the dead in dreams would be looked upon as sufficient evidence for this.

The same line of interpretation could lead to the belief that animals and plants had souls of this same immortal, invisible kind. In dreams and visions both animals and plants sometimes held conversations with the spirits of men, which further complicated their relations to man and their mysterious behavior. Yet, primitive peoples did not stop here, for they assigned a dual existence to inanimate objects, which they believed to possess souls. From this it was an easy step to the belief that everything in nature had such an unseen presence, or was animated. To us this seems absurd, but the idea of a human spirit or soul is still one of man's most precious beliefs. The Christian nations scoff at the generous belief in souls common to primitive cultures, calling them pagan, contemptible, and savage.

You will notice that Tylor proposed a scientific explanation for the belief in souls instead of a divine or miraculous one. According to his explanation the existence of a belief in souls was as natural and inevitable as gravity. When a few human beings were gathered together, souls would be manifest. Everyone would take their existence for granted. The more philosophical among them would begin to speculate as to what a soul would look like if it could be seen. Most everywhere it was associated with the breath, which could be felt but not seen, death being a state in which the breath had left the body for good. Uncertainty as to where the soul went and what it did after death, led to fear and the formulation of beliefs about these wandering souls. Many

primitive peoples believed that for a time they came back home to flit around the fireside and to visit the familiar homesteads. Unfamiliar noises at night were explained in this way. From this it was an easy step to regard such returned spirits as vindic-



Museum of the American Indian

Fig. 20. Scaffold burial as practised by the Crow Indians of Montana

tive or evilly disposed toward the living. Illness, pain, accidents, and bad luck would be attributed to them, and procedures devised to avoid the visits of such lost souls.

Burial and mourning customs among the primitive are often explained in accordance with such beliefs. Thus food and property will be offered to the spirits of the dead for awhile to appease any resentment they may feel because of the indifference of their relatives. A few pages back we called attention to the practice of burning down the house after a death had occurred in it. Where this practice was observed, it had become a custom, was a part of the burial and mourning culture complex and so a pattern in the culture of the tribe. In such situations all individ-

uals were conditioned to it and so never questioned the correctness and propriety of burning down the house. Yet, if they were asked to justify the act, they would first be shocked or surprised that anyone should question the practice, then they would usually advance the belief that since the souls of the dead came back to visit the house, it was safer to destroy it and build a new house at another place to prevent the soul of the deceased from haunting the family and taking vengeance upon them.

The belief that inanimate objects, plants, and animals have spirits, or souls, leads to quite a different attitude toward the world and its contents than we might assume. When primitive man walks abroad he feels that he is in the presence of living creatures like himself and conducts himself accordingly. He recognizes that he is being watched and judged. A mysterious noise may be interpreted as singing and by the aid of his imagination he may compose a song which he will declare was communicated to him by the spirit or soul of the object he associated with the sounds. The usual pattern for interpreting a dream is to say, for instance, that a bear appeared before the speaker in a dream; then it became a person and spoke to the recipient, conferring upon him certain powers and knowledge, with the necessary instructions for singing and conducting whatever ceremony was required to transmit the power. Most of the rituals conducted by primitive people are explained according to this pattern.

We have no means of knowing how closely the dream conformed to this pattern, but if it varied somewhat, it could without difficulty be modified to conform to the desired pattern. We

have reason to suspect that the similarities observed between the several rituals in a culture may be explained in this way. Our reason for citing these examples is to call attention to a way the belief in souls may express itself in ceremonial practices.

Among some Indian tribes the use of plant medicines is explained in a similar manner. Thus a person may hear a voice, and stopping to listen decide that a certain plant is speaking. The plant then becomes a person and explains how certain diseases may be cured if the root or some other part of the plant is used as a medicine. After such a vision, the recipient gathers the plant and lets it be known that he is now prepared to treat the sick. The plant need have no medical properties whatever, the curative power is assumed to come from the spirit of the plant, or, as anthropologists say, "the plant is believed to possess magical power to cure the sick."

When game is killed, trees cut down, and roots dug out of the earth, primitive people often feel called upon to address the spirits concerned, explaining why they took these lives and praying that their spirits do not become angry and seek to be revenged. They may even make restitution by sacrificing some object to the appeasement of the spirits concerned. While this appears to us foolish and useless, the native man or woman regards it as serious and sensible. Probably if our culture had conditioned us to see spirits in all such objects, the procedure would seem correct. Not to do this or take some other obvious precaution against angering the spirits, would be the conduct of a crazy person. When a Navaho Indian plants and cultivates his corn, he looks upon

the growing plants as living beings, demanding his respect and consideration. He believes that the corn plants are dependent upon the good will of spirits in the rain, the earth, and the winds, and that the attitude of these spirits toward himself will have a great deal to do with the kind of corn crop that results from his labors. Consequently, he sets up a code of rules governing his conduct, prescribes sacrifices and ceremonies to be conducted at specified times, thinking that he has sound reasons for believing that such conduct is absolutely necessary to guarantee a good harvest.

When a people believe that spirits can do both good and evil to the living, it is easy to conceive of some spirits as eternally disposed to be evil, to harm men and women, to find joy in their pain and discomfort, etc. Other spirits are conceived of as specializing in kind, good deeds. Out of this may soon grow the belief in an evil and a good god, or master spirit, a common feature in many primitive religions. Even our own religion recognizes God and the Devil. But primitive people often go the full limit of consistency by assuming that a single all-pervading power extends throughout all phases of life and nature. Some of the Indian tribes do not conceive of a superior god who resembles a person, but think of him as an immaterial power or essence residing in nature and so manifest in all things. The name for this varies according to the language spoken. For example, in the languages of the Algonquin family the name is *manitou*. This term has been defined as a mass of ideas referring to an assumed unconscious relation between the individual and the outside world. It is involved in

all forms of religious belief and practice and is intimately associated with customs and usages that bear upon life and its welfare. It is a religious word and so carries with it the idea of solemnity, expressing a serious attitude and kindles an emotional sense of mystery.

William Jones, distinguished student of Indian culture, writing on the meaning of *manitou*, says: "The essential character of Algonquin religion is a pure, naïve worship of nature. In one way or another, asso-



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Fig. 21. A Sioux Indian ceremonial garment. The triangular area at the top represents the heavens, the left as seen at night, the right as day. The images of the sun and moon are shown as belonging to both day and night. The rainbow is obvious; the small circles represent hail. A moth symbolizes the power of the whirlwind and a mysterious figure the powers of the night. Dragon flies are believed to symbolize power, and the wavy side lines suggest thunder. All these symbols are prayed to in ceremonies as the sources of power to protect the supplicant



Fig. 22. Bust of an American Indian Medicine Man with symbolic painting and ornaments. The disks above and below represent the power of the sun. The crescents symbolize the moon. Upon the cheeks are star clusters, the Great Dipper and the Pleiades. All these symbols stand for the real objects and the spiritual or animate beings which are manifested through them

ciations cluster about an object and give it a certain potential value; and because of this supposed potentiality, the object becomes the recipient of an adoration. The degree of the adoration depends in some measure upon the extent of confidence reposed in the object, and upon its supposed power of bringing pleasures or inflicting pain. The important thing with the individual is the emotional effect experienced while in the presence of the object, or with an interpreted manifestation of the object. The indi-

vidual keeps watch for the effect, and it is the effect that fills the mind with a vague sense of something strange, something mysterious, something intangible. One feels it as the result of an active substance, and one's attitude toward it is purely passive.

"To experience a thrill is authority enough of the existence of the substance. The sentiment of its reality is made known by the fact that something has happened. It is futile to ask an Algonquin for an articulate definition of the substance, partly because it would be something about which he does not concern himself, and partly because he is quite satisfied with only the sentiment of its existence. He feels that the property is everywhere, is omnipresent. The feeling that it is omnipresent leads naturally to the belief that it enters into everything in nature; and the notion that it is active causes the mind to look everywhere for its manifestations.

"It has thus been observed that there is an unsystematic belief in a cosmic, mysterious property which is believed to be existing everywhere in nature; that the conception of the property can be thought of as impersonal, but that it becomes identified with objects in nature; that it manifests itself in various forms; and that its emotional effect awakens a sense of mystery; that there is a lively appreciation of its miraculous efficacy; and that its interpretation is not according to any regular rule, but is based on one's feelings rather than on one's knowledge."

Such attempts to define the concept of the manitou may be more confusing than helpful, but they imply that it is a feeling of a powerful presence in the materials of nature. In Dakota Indian speech the name is *wakanda*,

in Iroquois *orenda*, and in Polynesia *manna*. When confronted with an emotional thrill upon sensing such a presence, the native need but pronounce the appropriate term in the speech of his people, to be understood. Whatever is good or important in the world is sufficiently explained by saying that it is because of this vague mysterious quality.

Tylor's theory of animism has not been accepted without debate. Many social scientists consider that he has given too much weight to conscious formal thinking, whereas primitive man fell into the assumption of a spirit or soul unconsciously. On the other hand, no one denies that Tylor put his finger upon something which still survives in civilization in forms of speech and belief. His assumption seems to be that no matter whether primitive man came to assume the existence of spirits consciously or unconsciously, the situations in which he found himself made it inevitable that he should fall into such views. Man's fundamental mode of thought seems to have come into being with Neanderthal man, perhaps even before that. Given such a thinking behavior and the situations to which we have referred, the belief in spirits seems inevitable.

A second term, *animatism*, has been proposed to cover instances in which a living power is assumed to reside for a time in material objects otherwise regarded as inanimate. This would avoid the difficulty of proving that every material object is regarded as possessing a spirit at all times. As a matter of fact many primitive people do look upon many material objects as inanimate most of the time. This is a different matter from considering them as always possessing

incarnated spirits. All, however, regard it possible that a spirit may at any time animate such objects. Animatism, then, would satisfactorily explain the great number of charms, sacred images, and other symbolic objects in museum collections. The Indian tribes of East and Central United States cherished many "sacred bundles," most of which contained common objects in which spirits were believed incarnated at the time the accompanying ceremonies were performed. Prayers were addressed to the spirit powers temporarily residing in these objects. The so-called fetishes of the African "witch-doctor" and the *churinga* of the Australian natives also belong here. Going further afield, the relics in ancient Christian churches and the Torah of the Jews, the prayer wheels of the Mohammedans, the images of Buddhists, etc., also qualify, since these objects do not have souls of their own, but are imbued with spiritual powers. It is in this way that the manitou, *orenda*, *manna*, and the like, function in primitive thought.

Finally, Tylor had a scientific mind and called attention to the possibility of observing and studying the beliefs of men in the same way that their tools, weapons, and houses were studied. That scientific methods will apply to all of these is now evident.

MAGIC

Magic is a method usually looked upon as the antithesis of science. Science assumes that impersonal forces operate in nature and that every event can be explained, if and when these forces are identified. We say that malaria is explained by the discovery that a living foreign organism causes the disease and that the bite of a mosquito carrying this organism acci-

dently implants it into the blood of the victim. The mosquito merely happens to be the carrier of the disease. The primitive doctor, ignorant of these matters, assumed that a bad spirit entered the body of the patient and caused the illness, which could be driven out by some illogical routine, such as singing certain songs or burning incense. In this case he assumes that some spiritual or personal power can be called into action which will banish the sickness.

Perhaps a more familiar example may be chosen; a sleight-of-hand trickster often diverts the attention of his audience by stating that when he pronounces certain meaningless words, they will exert a mysterious power to transfer an object from his

hand to a hat upon a near-by table. In this case the performer knows that he is deceiving you. Primitive priests and doctors frequently fool the patient by tricks, as when they pretend to draw an object from the body of the patient. At other times, they try to bolster up the faith of their followers by sleight-of-hand performances. Often, however, they sincerely believe that if anyone happens to hit upon the right formula—that is, to sing the right song, to make the right gestures, etc.—the desired result will follow. Tylor thought this was to be explained by the belief that a spirit or a soul animated all things, that these spirits originated all the observable movements and forces in the world voluntarily, and that there were living personalities who could change their modes of action at will. Hence he considered his theory of animism explained by magic.

Another English anthropologist, by the name of Frazer, rejected this explanation. He argued that Tylor had reversed the order of occurrence. According to Frazer's way of thinking, magic was recognized and practiced before the theory of animism took shape in the minds of men. Since both Tylor's and Frazer's ideas were formulated as theories to be proven by evidence, we are not in a position to decide as to the truth in the matter. Notice that no one denies that primitive people possess beliefs in spirits or souls, and that they believe in and practice magic. There are questions as to which came into being first and whether one is an outgrowth of the other. So far no one seems able to present a convincing answer. It may turn out either that the two things are complementary to each other or that they developed simul-



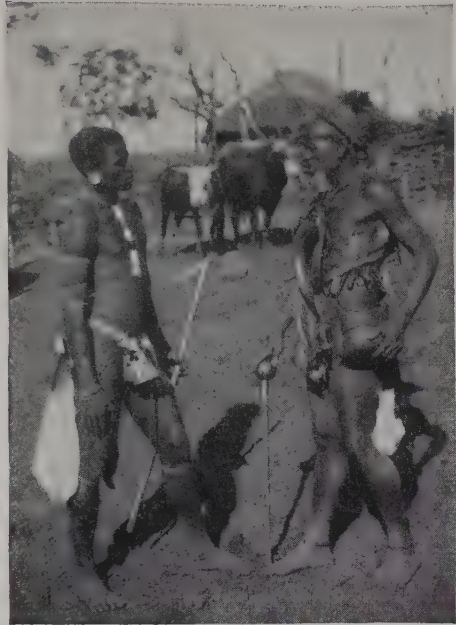
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Fig. 23. Wooden doll used as a charm by the Menomini Indians of Wisconsin

taneously. A scientific answer may not be possible but we can gather information as to how magic is used, where and when, and thereby come to know more about human beliefs than before.

This brings us to the point of trying to realize the functions of magical procedures in the tribal community. Some have limited the definition of the term magic to refer only to beliefs and practices that were common to the whole tribal personnel. One who has carefully observed a tribal community has little sympathy with such a distinction, because it is rare that any belief or practice can be said to be equally associated with each tribesman. There are usually doubters and non-conformists to disturb the even flow of life; there are also geniuses as well as morons and the sincere and the treacherous. It will be more profitable, therefore, to hold to the general characterization we have formulated, and to attempt no distinction as to the degree to which the tribesmen agree among themselves.

On taking up residence in a tribal community one soon senses the presence of a system of magic. Every field anthropologist knows that his tolerance by the group will depend upon the course of events and the magical system of the tribe. Should someone die or an epidemic break out, the inference may well be that his coming was the cause of the trouble, or they may go so far as to assume that the anthropologist is working magic against them. The writer once heard a veteran of Indian wars tell how hostilities were once started because the carpenter of a military post from which the Indians were supplied with coffins, undertook to anticipate the



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Fig. 24. Magic is frequently used in curing disease. A Zulu cattle owner is seen here requesting a witch doctor to cure his sick cattle

demand by making up a stock of assorted sizes. This was observed by the Indians and interpreted as preparation for the burial of those to be killed by the magic of the white man. To them, this was a correct interpretation, conforming to their belief respecting similar actions on their part, and their only hope in this case was to kill the white men before the spell was set in motion. The history of white contact with natives everywhere yields a wealth of similar experiences.

In part, magic is a pattern of interpretation and procedure called into use when confronted by a new mystery. When a taboo has been evolved, it becomes a device by which a dangerous situation is to be avoided. To

meet special and unexpected situations, the tribesmen seek aid from their leaders and at this point the shaman steps in. He renders a real community service, not so very different from that of the local physician. We can conceive that every primitive, however lowly, would subscribe to the maxim, "when in danger, do something." What he does, will depend upon the patterns in his tribal culture, particularly when the danger is invisible or wholly imaginary. If we have correctly stated the situation, magic furnishes the pattern for the "doing of something," or meets a real need in the community. The urge to find the right method seems to have been evident everywhere from the days of the cave man to the present.

In this instance, however, we set out to consider the place of magic in the community; our view of it, though hazy at best, will be clarified by attempting to answer the query: "Does the savage ever respond to happenings in any way, but through magic?" A thoughtful perusal of the literature will demonstrate that he does. Magic or no magic, he believes in keeping his bowstring dry, for the savage does order a part of his life by what we call "common sense." The physical conditions necessary for kindling and maintaining a fire are recognized and are not normally associated with magical ideas, so far as the evidence goes. Called upon to explain why fire exists, he may resort to magical conceptions, as did our ancestors, but he does seem to segregate many things in a class apart from the realm of magic. This aspect of the matter has been discussed by Carveth Read. "With the savage . . . common sense, Magic, Animism . . . these are the three great congeries of ideas that

compete for the control of his thoughts in his interpretation of the world."

One might truthfully add that to varying degrees these also compete in the thoughts of civilized man. Part of the difficulty in forming a satisfactory notion of the part common sense plays in all the vagaries of life is that it is so integrated with magic, that no one can be sure where one begins and the other ends. One may doubt that the leaders in tribal thought in any tribe will fail to feel a difference with respect to the reality of the common sense world and the realm of magic and animism.

In any event, what Carveth Read had in mind was that it would be far from the truth to assume that primitive peoples do not distinguish between the inevitable order of nature and such procedures as we have pronounced magical. The writer once watched some American Indians, curious spectators, as a trader was installing an electric cigar lighter. When everything was complete, the instrument was tried. The Indians were awed and pronounced it magic; but some weeks later, they had come to regard it as a mere mechanical contrivance. In short, what was once viewed as pertaining to the invisible powers, had now taken its place in the ordinary affairs of life as a mechanical device. This is not a unique case; the history of native adjustment to the ways of civilization will furnish other examples. Even a casual acquaintance with primitive peoples will show clearly a recognition on their part of a difference between the inevitableness of such effects as burning by fire, the falling of an unsupported object, of death, of hunger, etc., and the effects of magical procedures. In

other words, primitive man tends to regard the world of spirits and myths as somewhat apart from the sterner realities of life. In his mind the two things are not identical. In the everyday routine of life he expects fire to burn, want to bring starvation, and death to stalk through the camp. He is far less certain that any magical procedure will be followed by the desired result; or we may say that, while every member of the tribe will agree to the first, he will vary or qualify his beliefs respecting the latter.

The community will feel the need of magic only to the degree to which their culture demands it. Among some

Australian tribes, for example, almost every action in life is associated with magic and one may expect that in such a community, where sickness, death, and all the smaller ills of life are regarded as avoidable by magic, an improvement in the methods of magic will be welcomed as a public boon. So we read:

"Possibly the head man of the group of natives inhabiting that part, being of an ingenious turn of mind, set himself to work to invent some specially effective piece of apparatus wherewith to injure his enemies; for it must be confessed that, though he has many good points, the Australian savage is particularly fond of injuring an



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Fig. 25. Magic is often used to detect the guilty. Here we see a Zulu trial in which the defendant is required to prove his innocence by placing his hand in hot water

enemy when the latter is unable to help himself. A man who can invent any implement which is, rightly or wrongly, supposed to be especially effective and deadly, is regarded as a really great man and a benefactor to his people, in much the same way in which, among civilized nations, a Krupp or an Armstrong, a Maxim, a Brennan, or a Whitehead is regarded as one who has aided the particular nation with which he may be associated."

Finally, in social anthropology, the question often arises as to whether a given culture complex is social or antisocial. Magic has frequently been pronounced antisocial and, therefore, objectionable in any kind of society. This, like most statements of the kind, is too sweeping and too highly colored by our own sense of values. All magic directed toward social improvement and even the "black art" may be justifiable, provided the community is benefited by what it does to the individual. The modern objection to magic is not based upon the idea that all magic is antisocial, but upon the belief that it is inefficient as a method.

Science is often said to be the new magic of our day. A number of able scholars, Tylor, Frazer, Marett, etc., regard magic and science as "birds of a feather," whereas others rise in indignation at the suggestion, classing them as antipodal. The dispute hinges partly upon definition and partly upon the regard given to the function of the two institutions in society.

One of the chief reasons for opposing the idea that magic and science are functionally the same, lies in the contempt in which the term magic is now held. Thus Tylor, Frazer, and others make a good case for the unity of magic and science by showing that

in both immutable laws are believed in; that the mind works alike in each, dealing in causes and effects; and, further, each follows the principle of experimentation in its broadest sense. A person seeking a way to cause his enemy to fall at a distance may approach it from many assumptions: a scientist most likely begins with basic assumptions as to physical laws and may set up experiments with electricity and with other kinds of waves in the hope that he will chance upon a new relation of the forces involved; a primitive starts with the assumption that an invisible power can be invoked by an unknown procedure, and sets out to try modifications of procedures believed to function in other situations. As ethnographical data show, he frequently chooses lightning as the phenomenon with which to experiment. Since primitive man assumes that lightning is the act of a living personality, he tries to find out what will induce this personality to help his fellow men. The scientist, on the other hand, seeks to learn what physical conditions lead to a lightning stroke, and then to control those conditions.

Those who regard the one as magic and the other as science, say there is nothing in common here because the values of the methods for setting up and checking the experiments are not comparable. However, this contempt for the methods of primitive man and for his basic assumptions should not blind us to the apparent identity of psychological procedure. This is what Tylor seems to have had in mind when he spoke of modern science as an improvement on primitive magic.

One difficulty in dealing with this subject is that we speculate as to how primitives systematize their beliefs

and purposes. Few people have lived with any primitive group long enough to earn the right to speak upon this subject, but when such persons do speak, they are usually brief, or indicate that insofar as they could discern, the mind of the primitive worked about like that of the observer. This is what most theoretical writers have assumed, but, on the other hand, these observers of primitive life often set up an ideal of philosophic insight and logical consistency often far above the average attainment of civilized man. Perhaps this is why the stigma of rationalism is so often cast at men like Tylor, Spencer, and Frazer.

But after all, what is the truth of the matter? This is just as much a problem now as it was in Tylor's day, notwithstanding the pages and pages of printed data as to what primitives do and believe. Among those who come nearest the crux of the matter are those who assume the attitude of an understudy to a tribal seer. Those who have had this experience may be expected to have at least some dim realization of where the solution lies. In such cases as here cited, the European and the primitive differ in what each takes for granted, or does not question in his culture; yet the European will often be

surprised to note how completely his primitive teacher realizes the gulf between them and how ingenious he sometimes is in seizing upon and explaining the commonplace—but basic—assumptions in his own culture. In cases of this kind he generalizes, or repeats concepts on the theories of life taught him by his tribal teachers.

It is obvious that somebody, somewhere, and at some time, attempted to systematize and interpret the complex of beliefs and practices in the tribe. In anthropological literature one reads the records of these formulations and descriptions of observed practices. The impropriety of accepting the native explanations of the origin of any practice is now generally conceded, but the primary question



W. H. Craft

Fig. 26. Certain African tribes believe that the witch doctor possesses the power of "smelling out" criminals by means of dice

of whether the first step in the initiation of the tribal pattern was a matter of thinking from effect to cause, or whether the association was wholly external and purposeless, still remains unanswered. This is, of course, a troublesome psychological problem which had best be left to specialists in that field. Even so, its answer might not help us in arriving at an understanding of the function of magic in the life of the group. Since magic in the large sense is found everywhere, even among ourselves, it is another universal phenomenon, and if it follows that wherever humans are gathered together, we may expect magic in some form, then we are face to face with one of the fundamentals in the human way of living.

These are but suggestions as to how the question of magic and science may be approached. No one has claimed that animism has contributed much to science, but, on the other hand, it is at least the background to philosophy and the large concepts of matter, force, vitalism, free will, soul, etc. It has enriched literature and art; figurative and poetic speech is in large measure based on animistic materials, and even science frequently resorts to the use of the animistic vocabulary to make itself understood. Magic, on the other hand, frequently shows unmistakable tendencies to postulate an unfailing order of events, a fatalism not unlike that assumed by science. Magic assumes a source of power, which, through trial and error, may be brought to do our will, and in that sense takes on the plumage of science. Savage magicians have frequently used physical and chemical reactions to demonstrate their beliefs, as in the fire walk, plunging the hands into boiling water, etc.

One thing is clear, however, the primitive scientist and the magician were rarely differentiated by the community.

In this connection, we may be reminded that one striking difference between primitive and civilized man lies in their methods. Time after time, it has been demonstrated that when civilized man seriously undertakes to compete with the savage he can outshoot, outdistance, and overreach him point by point, and, when analyzed, the chief factor is always found to be superiority of method. The civilized techniques for meeting a situation, for analyzing and directing one's forces, are far in advance of the primitive. Some people decry the idea of progress and evolution in society, asserting that the ratings, civilized and primitive, are pure fiction, but the history of knowledge reveals a relatively steady advance in the understanding and mastery of nature and of man himself. It may be correct to say that at one end of this series stand the methods of science, with magic at the other; still we suspect that the process has been one of specialization and refinement rather than the substitution of one for another.

It appears, then, that magic is a term used for a method of procedure highly characteristic of primitive communities, but by no means absent in civilized society. It seems to us like a childish game in cause and effect, because we have better methods. There is no great difficulty in observing and describing what is done in a given community when a concrete situation arises, but to interpret this in terms of psychological or social response is still baffling.

The chances are that the definitions of magic so far given are inadequate

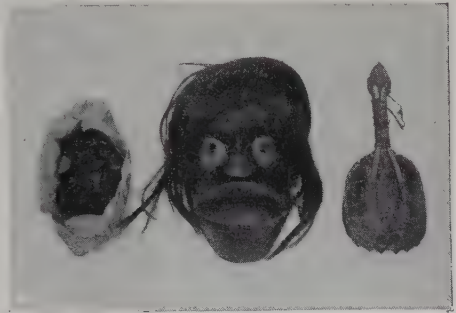
and in part misleading. We can, at this time, feel reasonably sure that one of the most widespread responses of man seems to be his awareness of an external power, which may remain undifferentiated on the one hand, or be rationalized into a system of powers on the other. This may or may not play a large role in what we have called magic, for viewing the practices of the shaman in the large, he seems to be groping after the unseen by acting out the procedures that work among the seen. He knows that he can get a point out of a wound by pressing or sucking, so with the same technique, he pursues the unseen cause of a pain. When he seeks the unseen, we call it magic, when extracting an observed object, primitive surgery. If, then, we seek a meaning for the term, we find ourselves involved in a matter of values; common sense and science, we admire; magic we abhor.'

It has been assumed that a kind of animistic philosophy is at the bottom of magic, a belief in a capricious living power that might be persuaded to do one's will; but also the contrary, a theory that there was an order in nature, which, if one had the requisite knowledge, could be manipulated as precisely as a door may be opened and closed. In each tribe occur procedures calling for these theories in turn, but we cannot be sure that they are recognized by the native with sufficient clearness to lead to the creation of new procedures. In short, the efficacy of such theories in revealing origins, or the "reasons for being" of magical procedures, may well be doubted. They may equally well appear as universal community responses and later be dignified by the formulation of a tribal explanation.

The problem in magic, then, is, aside from the recording of more data, to study the responses entering into these primitive procedures.

MYTHOLOGY

Myths constitute the unwritten literature of peoples, especially of those who do not practice writing. We use



Museum of the American Indian

Fig. 27. A wooden mask, bag of tobacco, and a turtle shell rattle used in doctoring by the Seneca tribe

the term here as synonymous with folklore. There is a large element of fiction in these narratives, usually in prose but including the texts of ballads and folksongs. Scientific interest in mythology began in Europe with the studies of the Grimm brothers, who early in the nineteenth century began to trace myths and mythological characters through the ancient languages of Europe.

Not only were many folk-tales obviously versions of a single tale, but many of the mythical heroes appearing under different local names seemed identical in origin. This insight of the Grimms fired the learned world with zeal for research in mythology. Folklore societies came into existence in both the Old and the New World, all directing their energies to the collection of myths and

tales and their interpretation by comparative study.

The Menomini Indians believe that their folklore and myths fall into four classes: sacred myths, trickster myths, "fairy tales," and "true stories." Finally, the investigators, Alanson Skinner and J. V. Satterlee, segregated a group of tales which the Menomini borrowed from the white man since the colonization of America. In all, the Menomini collection contains 134 narratives in the above classes, as follows: (a) sacred and trickster myths, 25; (b) "fairy tales," 42; (c) true stories, 62; (d) European derivatives, 5. Skinner believed that this collection contained about all the folklore and mythology current in this tribe in 1910-1914. As this total approximated that for a number of other tribal collections, it is indicative of the volume

of mythology an ordinary tribe can conserve.

Turning now from volume to subject matter, we find that classes *a* and *b* deal with the creation of the world and a few similar topics, but refer mostly to the actions of a culture hero, or a god, who is held responsible for the present order of life. The third division, spoken of as "fairy tales," comprises a miscellaneous collection partly humorous, but in all of which there are magical practices on the part of persons and animals, quite out of keeping with everyday experience. The class, "stories true to life," deals with adventures, ghosts, visions, etc. We see, then, that this collection of narratives corresponds in range to a national literature. If tribal historical legends and current autobiographies had been added to the above,



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Fig. 28. Drawing by a Shawnee Indian showing a Peyote Cult ceremony. This is a modern example of a ceremony widely diffused among United States Indian tribes



Museum of the American Indian

Fig. 29. Southern Cheyenne Indians of Oklahoma painting their faces and bodies for participation in a sun dance ceremony

the unwritten literature of the Menomini would have been fully covered. Yet, something remains, because the various ritualistic ceremonies of this tribe contain songs and speeches which are largely fixed in outline. This, however, brings the picture to a fair state of completion, and gives the general outline of what may be expected in any tribe living under similar conditions.

A body of mythology of this kind tends to survive after the culture changes. For example, the Menomini Indians have now come to live much like white men, but many members of the tribe can still tell the important tales in their mythology. Their survival is rendered easy because they do not conflict with the changing economic life of the tribe and because of their literary qualities. In former days

these tales carried the ideas and ethics of the tribal culture, as do the sacred books and literature of cultures using writing. In anthropology, these tales are important in that a comparative study of them will show how some tribes have borrowed tales from others, and if the geographical distribution of tales is plotted on a series of maps, they should in that way reveal the directions in which cultural influences have traveled. A study of Old World myths and of those collected from the surviving Indians of the New World shows how most of the outstanding tales of the latter have diffused across continents, but that few of them have crossed from the Old World to the New. We infer, therefore, that society in the New World has been separated from that in the Old World long enough to

acquire a distinctive body of tales and to distribute them widely.

It has been found difficult to distinguish between philosophy, mythology, religion, and ethics, when dealing with the beliefs of primitive peoples; thus, it may be wiser to accept the mass of beliefs as found rather than to attempt to differentiate between religion, philosophy, and the like. One of the latest general discussions of primitive religion is by R. H. Lowie, who is inclined to define religion in terms of feeling only, and therefore as realized in unusual and special experiences.

Paul Radin, writing of the religion of the American Indians, considers two factors important in religion, "first, a specific feeling; and, second, certain beliefs, conceptions, customs, and acts associated with this feeling." He goes on to say that among the beliefs so associated, those referring to spirits take a prominent place, but that, on the other hand, it frequently happens that religious feeling is associated with rituals or even with simpler procedures.

In any case, as just stated, a tribal religion is to be sought in a complex of beliefs and practices. Data upon the former consist of written statements by European observers, professing to record the substance of formalized beliefs, which are recognized and transmitted or taught in the tribe. Such accounts are prone to be colored by the interest of the investigator and to vary in completeness with the persistence of his inquiries among the tribesmen. Mythology, however, can be employed as a partial check upon basic beliefs; partial, because we must not take for granted that all the important beliefs of a tribe will be found in these narra-

tives. It frequently happens that a group of shamans or priests will maintain a body of beliefs and practices which does serve to guide the community at large, but which is not embodied in mythology. And in all cases the field investigator must get his data in the form of instruction, usually imparted by the best minds of the tribe.

BASIC BELIEFS AND RITUALS

Anthropology offers a respectable body of knowledge on tribal beliefs. We have reviewed some of the types of beliefs which have persisted ever since primitive times, as animism, animatism, totemism, and magic, all of which seem to be based upon a primitive philosophy that the universe is animated by a personal power which can of its own free will change the normal order of events at any time. This philosophy, and the belief in which it is expressed, functions in ceremonial rituals.

Such ceremonies may vary from complex and long-drawn-out procedures to those of an hour's duration or less, and may involve most of the tribe or range down to what may require only one or two persons. Viewing modern anthropological literature as a whole, we see that something more than half the pages given to specific accounts of tribal cultures deal with ceremonies. First of all, a ceremony may be either religious, magical, or little more than social, and just as we found it unprofitable to decide what were religious beliefs and what were not, so we may now put aside the temptation to classify ceremonies as religious, magical, etc., for any one ceremony may well be all of these at once. But to discuss the characteristics of a phenomenon like this, one must first have some famili-

arity with it in the concrete. Any good monograph will answer; but we may cite a few examples of tribal ceremonial systems.

Choosing a tribe about which much has been written, the Piegan, a division of the Blackfoot Indians, with

3. Pipe bundles. These are important objects, containing large, decorated pipestems, a number of animal and bird skins, paints, etc. One outfit examined contained 47 objects in all. The ritual is long, comprising from 49 to 56 songs. In all, there were 17



Fig. 30. A ritualistic bundle

whose culture the writer is familiar, we may enumerate the observed ceremonies as follows:

1. The annual sun dance. This extends over a period of eight days, and is participated in by the whole tribe. With this ceremony goes a sacred bundle with an elaborate ritual and many songs. Eight such bundles were observed and their rituals could be performed independently of the sun dance.

2. The beaver ceremonies. These are performed with a large bundle of sacred objects, require ten or more persons, and must be given at the sound of the first thunder in the spring, but may be given at any other time. The ritual is long and complicated and the songs are estimated at more than 300. Only a few men claimed to know the whole ritual, the learning of which was regarded as a feat of the greatest importance.

such bundles in the tribe, the rituals for most of which possessed individualities.

4. The bear knife. A small bundle containing a special knife, among other objects, and accompanied by an important ritual. At the time of observation, one bundle existed, but a number of men knew the ritual.

5. The sacred lance. The chief object in this bundle is a lance about three feet long. Ritual elaborate.

6. Otter bundles. The whole skin of an otter and accessory objects, with which goes a ritual containing 49 songs. There were two bundles.

7. Buffalo rock bundles. These seem to be archaic bundles, each with a short ritual containing seven songs.

8. Painted tepees. A common type of bundle which was associated with styles of painting for tepees, or tents. Twenty of these were observed in the tribe, the tepee decorations and

rituals all differing in some details. Their rituals were moderately elaborate, containing songs ranging from four upward.

9. Other rituals. The following classes of objects each had a ritual with songs; shields, weasel-tail suits, hair-lock suits, headdresses, war bridles.

10. Sweathouse rituals. The use of the steam bath requires a ritual with a number of songs.

11. Finally a series of eleven societies for men, age societies, are maintained, each with a ritual. To this should be added three cults and two dancing associations.

Thus we see that for this tribe are listed more than 75 ceremonies, for each of which there is a ritual con-

taining songs, prayers, and the orderly handling of regalia and sacred objects. Certain similarities appear in the ceremonies, in that in most cases the important feature is a bundle of objects which is never opened except in the ceremony, which is again largely a matter of opening the bundle and demonstrating the objects within. This is a kind of tribal pattern, which may or may not occur among some of the neighboring tribes. The number of adult persons in the active tribal membership at the time this list was compiled was estimated at a thousand, of which about half were males. Only a few of this number knew these rituals and songs well enough to lead in their performance. We thus get an idea of how much



Museum of the American Indian

Fig. 31. A sweathouse used by the Plains Indians. Water is poured over hot stones to produce the steam which is used as a purification bath

ceremonialism such a tribe can carry in its normal life.

It is commonplace that in a ritual, the form of the ceremony resists change. At least it is slow to change, because it is conceived as having been handed to society by a higher power and is valuable only in proportion to its identity with the original. Another important characteristic is that a large part of the tribe's mythology narrates the events leading up to the origin of the ritual. Most American Indian ceremonies open with the recital of the narrative of how the ritual was originated and the attendant circumstances. Further, the ceremony then follows as a kind of dramatization of the myth. All primitive ceremonies contain songs, which are regarded as the vital parts of the ritual, perhaps because they are fixed in word and music. Whatever magical power the ritual is believed to harbor emanates from these songs. It follows, then, that the symbolism of such ceremonies not only expresses the basic philosophy of the tribe but a great deal of its mythology as well. To understand one we must know a great deal about the other.

PRIMITIVE SOCIETY

Man living in the natural state knew nothing of nations or kingdoms. He lived in small camps or communities, each self-contained and independent. The only restraint upon the individual was the will and power of the group, yet strange to say this discipline was usually effective. The individual who set his face against the community came to grief. Every one respected the requirements of the group's culture and hesitated to defy them. They feared the power of the unseen, the imagined super-human



American Museum of Natural History

Fig. 32. A Mohawk chief. An old painting in the New York Historical Collection. The totem animal of the chief's clan is represented, probably a wolf

powers in nature, no more than they feared the disapproval of their group. Above all else, they placed the respect of their fellow men and shrank from their ridicule. No primitive people about which we have knowledge can take loss of social status lightly, and forceful ridicule will often cause them to seek refuge in the wilderness or among strangers, or to end their lives in battle or by suicide. Thus the community has in its hands powerful mechanisms for discipline.

The older men and women control the camp, since they are the authorities on customs and techniques of living, the keepers of tradition, my-

thology, and beliefs. The younger people defer their opinions to those of their elders and obey their orders. These older people, especially the men, confer upon the questions of the day and so formulate opinions which are final. This is why the young folks stand in awe of them. These old people are conscious of the fact that the preservation of the culture is their responsibility and so keep an eye upon the training of the children to see that they are fully conditioned to the authority of their elders. White people usually speak of these older men as the council, or the head men, because of their disposition to confer with each other daily. Usually some one man dominates because he has a forceful personality, and is intelligent and judicial, but he will be looked up to only so long as he commands their respect. If he lives too long and becomes feeble, the next best man will gradually displace him.

As we have said, the social unit is the community or camp. Whatever else can be set down as characteristic of primitive man, it is clear that he is a camp dweller. The family, or the married pair, may be an essential unit in the social structure, but it is not the culture unit. It is not the family that has a culture but a group of families. However, a number of camps may be neighbors and possess a culture in common, if they speak the same language. In such cases they may take the first step in organized government by recognizing their identity in speech and culture to form a kind of federation, or tribe. The control of matters important to the camps or villages as a whole is in the hands of a tribal council made up of the leading head men from each camp in the tribe or social unit.

Among this body of men there will be a recognized leader who has the necessary qualifications and who demonstrates his fitness to assume the responsibility. One of the important duties of the head man of each camp is to mediate quarrels and adjust injuries. He steps in to avert resort to violence, and operates by mediation, calling attention to the impropriety of disturbing the peace and, if possible, pledging both parties to arbitrate. As soon as a dispute begins, the head man steps in to do what he can. The tribal head man steps in when the dispute is between members of different camps and looks for assistance to the head men of the camps concerned. The function of the head men is to smooth over the difficulty so that the two camps will not resort to arms, for once the members of one camp go so far as to kill or even injure a member of the opposite camp, the camps can no longer live in peace within the tribe, but one of them, at least, must move away to join a strange tribe or live alone.

When one or more camps are attacked by an outsider the others are called upon for retaliation. In case a war party is formed, it must have a leader of recognized merit. This function may be assumed by the tribal head man, or a younger, vigorous man may be called upon. This relation is often formalized by designating the war leader as war chief, whereas the regular head man in the tribal council becomes a civil chief. The pueblo Indian villages in New Mexico and Arizona had two such officials, as did many other tribes in different parts of the country. These federations of camps, or villages, into tribes were loose and voluntary. Each was jealous of its own freedom of

action and its right to settle disputes between its own members without interference from the leaders of the other camps in the tribe. If one or more camps dissented from the opinion of the tribal council, they were free to withdraw and live apart, though that might be dangerous because of their inability to defend themselves against hostile tribes invited by their isolation and detachment.

We can now see that wars between such tribes are for glory and plunder, not for conquest. The rule is to destroy the enemy rather than subject him. Children and young women were sometimes captured because they could be conditioned to the camp culture, but adults were killed on the spot or tortured to death in the home

camp. The exceptions to this begin with the formation of barbaric nations. For example, six Iroquois tribes in New York State formed a league of tribes, a kind of super federation. In time they conceived of subjecting other villages, requiring them to furnish fighting men and pay tribute. These were not permitted to make war on other tribes except under the leadership of the Iroquois. They could manage their own internal affairs, but had no voice in the league council, which dictated to them in all inter-tribal relations. Here we see the beginning of imperialism.

RELATIONSHIP SYSTEMS

One of the functions of camp government is the control of sex relations. The formal technique for such



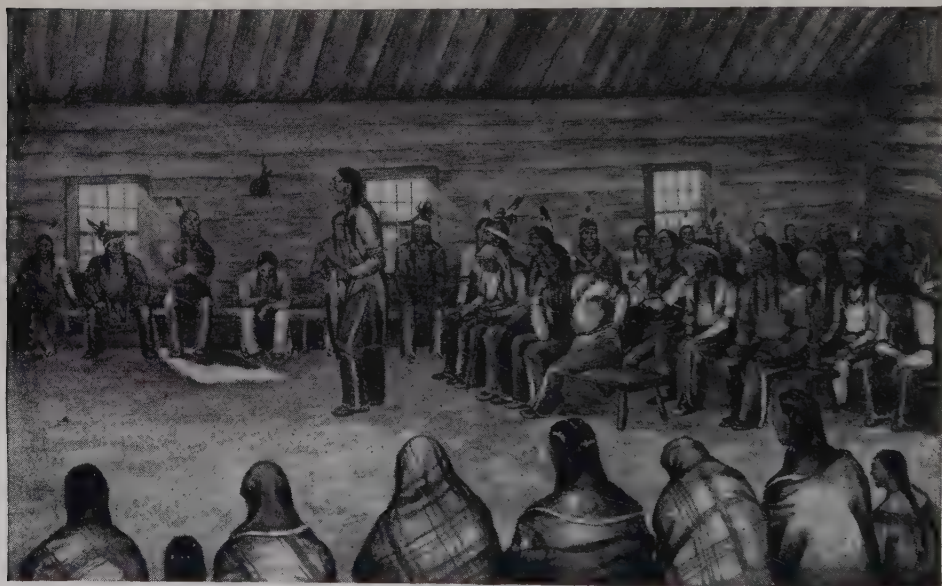
Museum of the American Indian

Fig. 33. Native governors of the Zuni Indian villages of New Mexico

control is a definite form of marriage, as opposed to a condition of promiscuity. Even the crudest of primitive societies sets its force against promiscuity, for so far as observation

and of brother and sister. They differ as to the marriage of cousins and persons of other degree of relationship.

However, a great deal of attention has been given to relationship sys-



Rochester Museum

Fig. 34. Representation of a council of the Iroquois Indians in 1800

goes, the whole culture breaks down as soon as such a state prevails. Social anarchy then results and population declines rapidly. This alone would bring it about that marriage survived and became the rule. Opposed to the concept of general promiscuity, are incest and adultery. Accordingly, we find in all primitive speech, systems of classifying parents and offspring, but the systems are by no means identical. Whatever may have been the origin of the custom of defining relationships, it seems that one function regarded as important even in primitive society, is that of defining incest. The one universal reaction of all peoples is to frown upon the marriage of parents and children

tems since their discovery by the American social philosopher, Lewis H. Morgan, about the year 1858. Morgan first noted that in the speech of the Iroquois the word *haje* was used for older brother, but also to designate father's brother's elder son, mother's sister's elder son, father's father's brother's son's son, etc. The principle of this classification seems to be one of relative age or generation levels, at the same time distinguishing between male and female lines of descent. The whole concept was much more tribal than the narrower sense of family as we now understand it to mean a blood relationship. The generation levels of the person speaking can be represented thus:

<i>Generations</i>	<i>Relatives</i>
4	great-grandparents
3	grandparents
2	parents
1	older brothers and sisters
0	self
1	younger brothers and sisters
2	children
3	grandchildren
4	great-grandchildren

Theoretically there could be a few more generations, but the span of life is so limited that taking note of them would be impracticable. For example, in our own speech system uncle and aunt stand on the same generation level as our parents. In the Iroquois system, their sons would be our elder brothers also, instead of cousins as we designate them, and so would the grandsons of our great-uncles and great-aunts. By checking this over you can see that the name "brother" applies to all males upon the same generation level. In the same way "mother" would apply to all the women of the preceding generation in our family line. This seems absurd to us because it disregards degrees of blood relationship. Morgan first thought this was just a peculiarity of the Iroquois, but when he found, in 1858, that other tribes of Indians speaking different languages had similar systems, he suspected that there was a primitive form of relationship systems in contrast to a civilized form. He was disposed to seek the answer in the marriage systems of the peoples concerned.

He noted that among the Iroquois the son inherited through his mother or mother's sisters in contrast to our mode of inheritance through the male parent. He thought this the primitive condition because under the necessarily crude marriage systems at the

outset, the identity of the father would be uncertain, but the identity of the mother absolute. In short, Morgan thought there was evidence of an evolution of the marriage system, which could be discovered by a survey of the relationship and marriage systems existing among the peoples still living.

In consequence, a great research interest was shown in the forms of marriage and relationship systems, which led to a gathering of data from all parts of the world. In the main, the hopes of Morgan have not been realized but a great deal of information about these culture complexes has been accumulated. They are true culture complexes or patterns, since they are borrowed and diffused over culture areas like other culture complexes. They have geographical or regional distributions which suggest their places of origin and their history. The classification systems of relationships are arbitrary, like most other classifications, and so contain a number of arbitrary classification concepts, such as considering all women on the same level as the mother, as of the same relation by blood as one's real mother. When the native thinks about this, he realizes its artificial nature, but justifies it on the ground of usage or custom, which is to say, that is the way his culture decrees it.

DUAL DIVISIONS AND SIBS

Our attention so far has been given to such cleavages in the tribe as could be explained in objective terms, but there are other widespread types of segregation within the tribe not so readily interpreted. One of the most intriguing of these is the dual division. It has been observed that many primitive tribes recognize two classes,

the number of men, women, and children in each being about equal. In the older literature these halves of the tribe were called *phratries* and later *moieties*, but they are now usually designated by the simpler term, dual division. When such a dual division exists, the two divisions have specific names. For example, among the Sauk and Fox Indians, whose survivors now live in Iowa, we find such a dual division; at birth each child is assigned to a division, which affiliation is for life. These two divisions, or parties, seem to function in competitive games, the players from one division contesting with a team from the other.

Something like this seems to have existed among a number of other Indian tribes and also among the western Eskimo. Some of the Iroquois recognized the dual division, to which Morgan, who first studied the Iro-

quois, gave the name *phratry*, but in this case one became a member automatically by birth, and such is the rule wherever dual division exists, the cases cited above being exceptional.

As we review the tribes of the world, we observe many and various distinctions in the duties of division members and the parts they play in tribal life. In Australia and certain adjacent islands, marriage rarely takes place within one's own division, but a man or woman must always seek a mate from the other half of the tribe. The discovery of this custom strongly impressed McLennan, as well as others of his time, as the primary function of the dual division. They made the assumption that primitive society recognized the evils of inbreeding and in response to this situation evolved a series of customs to prevent the marriage of blood relatives. This idea is still considered favorably by many writers on social organization, possibly because they can see no other rational explanation for the existence of such divisions. In this inability to find a satisfactory explanation may lie the lure of the dual division. Rivers saw in it the basic elemental division of society, and so assumed that it was once universal and that wherever now present, it is a direct survival of the original primitive condition.

This view of Rivers is often rejected by anthropologists on the ground that there is no way of proving that each living tribe once had a dual division. This, however, overlooks the fact that tribes are still forming in some of the out-of-the-way corners of the earth and doubtless have been for ages, in which case they are like rather than different from the parent; hence, it would only be in tribes



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Fig. 35. Detail of architecture in a Hopi village

where the original dual form has passed down unchanged that it would be encountered. Proof in either case seems impossible. On the other hand, there may be some factor in human behavior that makes for the dual division when conditions are favorable, and so its appearance with respect to the time and place might be accidental; once set up in a tribe, it might well be stabilized by associating with it a few important social functions, for example, the regulation of marriage. This is pure speculation. In any case, the basic significance given to the dual division by a number of social students seems to us not fully warranted, but it does seem that we are justified in regarding the dual division as important whenever and wherever it is associated with marriage or with equally fundamental social institutions. Certainly the evidence so far does not warrant the conclusion that the setting up of a dual division was a response to fear of incest, as some authors propose.

Usually, when dual division exists in the tribe, the units are grouped accordingly, so that all members of a given unit will belong to the same division. Further, we noted that what were bands among the simpler folk corresponded to ancestral classes in more highly organized tribes. To such, the name *sib* is now given by anthropologists. Morgan called them *gentes*; other writers, particularly the English, used the term *clans*, while the American school used both, as previously stated. These divisions are considered of great theoretical importance and find a large place in theories of marriage, ceremonialism, and even of government.

It happens that the sibs of some tribes were reckoned in the line of

the mother, others in the line of the father, and, for convenience, the term clan was applied to the former and gens to the latter. Thus, if we read that the Zuñi Indians have a system of clans, we know that they are subdivided into sibs according to their mother's affiliation. If the name for one of these sibs should be Eagle, then all the children of an Eagle woman would automatically be classed as Eagle, and subsequently, the children of all her daughters would be Eagle, and so on. On the other hand, in a tribal system in which the children followed the father, these subdivisions would be called gentes.

Morgan believed such tribal divisions to be the original human groups and conceived the tribe to be a later step in the evolution of modern society. The reasons for doubting this are various; while it is true that a band, when large enough, can maintain all aspects of a culture, it is so clearly a subdivision and subordinate in vital matters, that its most natural origin would appear to be as a segregation within the tribe. However, we are now concerned with the subdivisions and the functions of a tribe as such, and in this respect Morgan was fully justified in placing great emphasis upon the basis of classification giving us sibs. The sib, as we have seen, is a line of kinship reckoned through a single parent to the exclusion of the other. Adopting such a system of relationship, there are two simple ways in which individuals could be automatically assigned to a sib at birth, either through the mother or the mother's husband.

Assuming that in the Zuñi tribe, as referred to above, an Eagle woman marries a Badger man, and that the

children are born into the clan, then the children would be Eagle. If inheritance were through the father, or gentile, as we say, then the children would be Badger. Thus the alternatives are clear. The operation of either rule—inheritance through the mother or through the mother's husband—would automatically sustain the system in the tribe. This will become clearer as this study advances, but to round out the picture, let us keep our attention on the Zuñi, and on classification through the mother.

Among the Zuñi one's father is not a true member of the family in the European sense; he is little more than a guest in the house. His responsibility to the children is far more remote than that of the mother, and this distinction is reflected in the kinship terms of the tribe. On the other hand, the mother's brother is regarded as the male in whom responsibility for the child is vested. This example may serve as an illustration of how customs respecting the classification of relatives tend to be reflected in the nomenclature for relationships; at least we need not be surprised to find that frequently the terms of relationship are not the same for the two parental lines, and are more complete in the line through which the classification is made.

Sibs play an important role in regulating marriage. For example, the rule that members of the same sib, clan, or gens, cannot marry prevents the marriage of certain groups of relatives. In a clan system the children of a mother cannot marry and so automatically brother-sister incest is avoided. However, unless another rule is set up, a father could marry his daughter because they are members of different clans.

Such rules do exist everywhere, but it is clear that the sib is not in itself a sufficient social mechanism for avoiding incest. This is one of the reasons for refusing to believe that a sib system originated in an effort to avoid incest, even though it does restrict the danger of incest. The most that can be claimed is that sibs are classification groups according to descent either in the line of the mother or in the line of the father. Further, some peoples do not apply the rule that sibs cannot marry, but decide all considerations of marriage upon the basis of blood relationship.

When the dual divisions are in function, custom frequently assigns sibs to one or the other. Thus, among the Iroquois, we find eight sibs (clans) as follows:

First Division

1. Bear. 2. Wolf. 3. Beaver. 4. Turtle

Second Division

5. Deer. 6. Snipe. 7. Heron. 8. Hawk

This is the way this system works in marriage. Originally a member of the Bear sib must marry into either the Deer, Snipe, Heron, or Hawk sibs. If a Bear woman married a Deer man, the children would be automatically members of the Bear sib, etc. The mother's brother (a Bear) would be responsible for the training of her sons since their father is a Deer and neither a member of their sib nor of their division.

The Australian natives maintain a far more complicated system of sibs in which marriages are chiefly between a pair of sibs while the children are by fixed rule members of a third sib. These Australian systems fall into two types: (a) in one a man may only marry a daughter of his mother's brother or of a woman who

stands to him in equivalent relation; (b) in the other he marries his mother's mother's brother's daughter's daughter or some woman standing in equivalent relation. Marriage would thus be restricted to cousins, with but few exceptions, while in the second type he could marry only a cousin of the third order, except the unlikely marriage with his father's mother. Thus, as a bar to inbreeding, the second type of sib linking is almost the ideal.

TOTEMISM

Totem is derived from an American Indian word, a name for an object, usually an animal or a bird, which symbolizes an individual or a family guardian. While totemism as a world-wide phenomenon was first sensed by McLennan, Frazer is usually regarded as the originator of the concept. One of his definitions for totem is:

"A totem is a class of material objects which a savage regards with superstitious respect, believing that there exists between him and every member of the class an intimate and altogether special relation."

The phenomena are by no means simple, since three main types are recognizable:

1. Sib totems, or cases in which the totem is equally related to all hereditary members of the clan or gens. These are also regarded as the most common form of totem.

2. Sex totems, like those reported from parts of Australia, where all the males of the tribe have one totem, the females another.

3. Individual totems, the type first described by Long, familiar to students of the American Indian under the name individual guardian.

The widely diffused tendency of sibs to have animate names is responsible for a great deal of speculation as to the social significance of the totem. Above all it is a sib, or family, name and, as such, comes to stand as the designation for exogamic groups in society. Then the tendency seems to be to regard the totem as the



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Fig. 36. A saddle of Indian make which copies the type of saddle used by white people in the nineteenth century. An example of diffusion

mythical ancestor or founder of the family. In any case, the members of the sib consider themselves as related to the totem and so to each other. The totem in this case symbolizes or expresses that quality of obligation expressed in the term kinship.

Some students of totemism have contended that it was universal in society, but this is not in harmony with the data. Because of its limited distribution and because there is not good evidence that it once prevailed among the ancestors of European peoples, and for other reasons, too, it is generally admitted that totemism is not universal and so need not have arisen as a direct natural response to situations of a single type.

Totemism is extremely variable in its content and is prone to associate with itself many traits of the tribal culture in which it occurs. All writers upon the subject have found it difficult to frame a definition that would clearly apply to all examples of the phenomenon, for no two tribal systems seem to be exactly alike. There are regional differences, as in North America, where the guardian spirit seems to be the keynote of the totemic idea; in Africa, the emphasis is upon the taboo against killing, eating, etc.; in Australia, the ancestor relationship is the outstanding feature. But even within these regions we encounter great variations as we pass from tribe to tribe. This lack of absolute similarity between the totemism of different tribes has led the ultra critical to deny the reality of totemism and to regard it as the selection of certain traits of culture on the assumption that they spring from a single source; their view is that the characters, we have enumerated, the name, taboo, descent, and brotherhood, should be considered as separate culture traits which just happen to occur in the same tribe. We should have, then, instead of one problem in totemism, some four or five separate problems. This point of view would, however, ignore the frequency with which the animal name is found in association with the taboo, etc., a fact for which an explanation is wanting. On the other hand, the majority opinion seems to be that totemism, as an association of variables with the recognition of a totem by the totemic group, is a reality. As to time of origin, there is no reason to believe that the institution is extremely ancient, and hence, there is little justification for regarding totemism as

the source of art, brotherhood, the first steps in government, etc.

Lastly, one may ask, what is the contemporary problem in totemism? The need seems to be for more exhaustive tribal studies in parts of the world where these can still be made, as in Australia, Africa, and certain sections of the New World. In all cases, however, it is not merely totemism that should be studied, but the culture of the tribe. That there is a totemic attitude among many groups of mankind, does not seem sufficient warrant for assuming that totemism is a principle that can be seized upon as expressing a distinct process in social life. If such a process is at work in totemism, it is still hidden.

THE FORMS OF MARRIAGE

Westermarck defines marriage as "a relation of one or more men to one or more women, which is recognized by custom or law and invokes certain rights and duties both in the case of the parties entering the union and in case of children born of it." This is a good working definition but the particular forms of association and the detailed obligations invoked vary greatly. However, the number of sex combinations in marriage are not numerous. The possible combinations are:

1. One man to one woman at a time—monogamy.
2. One man to two or more women simultaneously—polygamy.
3. One woman and two or more men simultaneously—polyandry.
4. Two or more men and two or more women simultaneously—group marriage.

The marriage system of any tribe or people must conform to one or more of these combinations because



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Fig. 37. Polygamy survives in the Philippine Islands. Here is a Sulu man with seven wives

they seem to exhaust the possibilities inherent in the situations involved. Taking the world as a whole, we see that all four forms of marriage do occur, hence, any particular form or pattern is a culture complex which will diffuse and have regional distributions like any other culture complex.

However, the four forms of marriage noted above are not mutually exclusive. Highly organized governments legislate on forms of marriage, usually accepting one form as the standard. In the Christian nations monogamy is the only legal form. No nation or people actually outlaws monogamy, this form is proper anywhere. Finally, it appears that some one or two forms of marriage are enforced in every society which is to say that no society exists without a form of marriage. Morgan, for example, assumed that originally mankind was promiscuous and that marriage sys-

tems, exogamy, and sibs were due to social evolution. There are difficulties in harmonizing this theory with the facts, since everywhere when a community becomes promiscuous its culture quickly disintegrates and the birth rate falls to the vanishing point.

Returning again to the distribution of pagan and non-Christian peoples, we find that polygamy far exceeds other forms of marriage, with monogamy next. These facts concerning primitive and pagan societies are accepted by many as proof that the original and natural form of marriage was polygamy, which is to say that "by nature man is a polygamous animal." Westernmarck, however, strongly opposed this interpretation. So the best we can say is that the question is still subject to debate. Incidentally, we note that studies of primitive populations in the hunting and gathering age are characterized by an excess of adult women, a condition which

makes some form of polygamy inevitable.

AGE AND SEX DISTINCTIONS

One characteristic of human classification systems is to utilize them in various unexpected ways. For example, sex classes are self-evident. Every language spoken makes this distinction, some even going so far as to assign sex to inanimate objects, as a female moon and a masculine sun. With such a bilateral division of the community clearly established, the natural thing to do is to agree upon secondary distinctions, or unnecessary distinctions, as in costume, manner of sitting, dressing the hair, etc. Occupational differences are arbitrarily assigned, as when some tribes require that all agriculture is the work of women, whereas among others it is the work of men; again, weaving is man's work among some tribes but the work of women among others. This is sufficient to show that there is nothing in these occupations functionally correlated with sex. There may be an inclination for each sex to avoid work performed by the other, but no indication of incompetence in either case. However, among primitive peoples the woman is usually the cook and the server of food. Yet, this is not wholly consistent, because in Australia the men usually cook the game animals they kill, while the women prepare the food they gather. After the men and boys have eaten what they want of the animal cooked, the remainder is passed to the women and girls.

Primitive people do not keep their ages in years but tend to class themselves as older or younger than their companions, yet they are put into age classes by menstruation, growth of

pubic hair, the menopause, and the onset of senility. Marriage is another definite distinction, parents and grandparents are also fairly definite groups. All these classifications serve as age distinctions and to each class are assigned certain tasks and obligations. Not infrequently men are classed as young married-men, married-men, and old men, and women in corresponding fashion. The general significance of these classifications which appear even in primitive cultures is that they are of fundamental importance to society and must be considered in all interpretations of culture processes. Further, they compel the assignment of tasks to the individual member of the community, in keeping with the abilities and experience of the individuals concerned.

Every successful culture must maintain patterns for the integration of age and sex classes by requiring that they live up to the standards in production and functioning which their culture requires. Further, biological conditions have a determining value in respect to the place of the individual in his culture. If the ideal of a society is to make the most efficient use of all of its members, then careful attention must be given to discover what tasks are suitable for each age class.

ARTS AND CRAFTS

In most books on anthropology we find such topics as economics, arts and crafts, material culture, etc., all of which refer to the homely matters of food, clothing, shelter, tools, transportation, etc. A varying part of the working time under any culture must be given to food production. When hunting, fishing, and gathering are

depended upon, the amount of time and energy devoted to these food-providing activities is relatively large. An Australian band on the march in the semidesert areas gathers up food as its members trot along from one waterhole to another. The scant supply leads to the use of all edible foods, roots, blossoms, grass seeds, stems of certain plants, acacia pods, fungi, berries and fruits, the larva of certain insects, honey, birds, eggs, snakes, lizards, small rodents, fish, and water animals wherever available. Of larger game there are many species of kangaroo, opossum, and the ostrichlike emu.

The normal procedure is for the women and children to pick up everything edible as the band moves along, while the men keep a lookout for larger game. Usually the combined efforts accumulate enough during the normal wakeful hours to supply food to all members of the party, but there is little time left for other matters. When ceremonies are to be performed several bands gather according to previous arrangement, a surplus of food having been accumulated for the short interval necessary. You will note that sufficient food is largely dependent upon shifting camp every day or two.

In contrast to this a central Eskimo band in winter, when living conditions are hard, builds snowhouses upon the ice in a bay or inlet where seals are usually to be found. Holes may be cut in the ice, and in these the women fish with hook and line. The men watch for

seals to be speared through their breathing holes in the ice. The village remains at this location through the winter. When seals grow scarce near the village, the men hunt in other places on the shore ice which can be reached easily by journeys with sleds and dogs. Once a seal is killed it can be taken to the village on sleds. Occasionally, a polar bear may be killed but the chief dependence is upon seals, supplemented by fish. The seal furnishes the oil used for heating as well as for food. The bear is a large animal, and the common seal is of moderate size, weighing 100 pounds or more. The cold weather makes the preservation of animal food easy, so that it is not difficult for the Eskimo to accumulate a moderate food supply. However, the village is seldom more than a week ahead, but that allows for a safe margin during a blizzard.

Now if we turn to the Iroquois Indians of New York State, we meet with a different pattern of economics. These Indians depended upon hunting for a large part of their food sup-



Fig. 38. An Eskimo woman fishing through the ice

ply, but raised a crop of maize, beans, squashes, and made a store of maple sugar upon which they could depend for a part of the year, since maize and beans can be stored over a long period of time, as could dried squash and sugar. It has been estimated that these foods might conservatively feed the population for a quarter of the year. Hence, the possession of such an amount of stored food would reduce the strain of hunting and conserve the game supply. The Iroquois did not weave cloth, so the deer skins resulting from hunting were necessary for clothing in any case. The surplus flesh of the deer could be dried and smoked, thus adding to the store. So in contrast to the Australians and the Eskimo, the Iroquois enjoyed greater security and could live in relatively permanent villages and enjoy the benefits of relatively denser populations.

The Pueblo Indians of New Mexico fared still better, living in large villages, raising about enough maize, beans, and squashes to feed them during the entire year, though hunting was practiced as a method of supplementing the diet. These Indians raised cotton and wove cloth, yet they did use the skins of deer and other animals. This seems a sufficient explanation of how these Indians could afford to build great apartment houses and live in them over long periods of time. So long as their farming land was productive they could live in the same place. By the help of tree-ring dating we can say that the ruined pueblo Bonito in New Mexico, for example, which could have housed 1,000 people, was occupied from 919 A.D. to 1130 A.D., or approximately 200 years. It is conceivable that had their lands not failed through drought or

erosion, their descendants would be living at the place still.

Such facts of material living come under the head of material culture, or primitive economics. Permanence of residence frequently leads to concepts of property in lands and in crops. Nevertheless, in primitive societies the individual ownership of lands is rare. The prevailing idea was that the land and what it produces are for the use of the community or tribe. Members of other tribes will be restricted or denied access to them to conserve their own tribal food supply. Yet as soon as agriculture appears, families, at least, and usually individuals, are considered the owners of the crops they produce upon a definite plot of land. However, the continuous ownership of the same plot is by no means conceded by the tribe.

As a rule, it is the duty of some official or experienced person to see that each worker is assigned a plot of land for the season, the right to plant in it and to enjoy what his labor and care produces. Sometimes the whole tribe joins in clearing the land before it is divided, again the custom may demand that the plots be assigned first, each individual clearing his or her own plot. Here and there, we note a tendency to permit an individual to have the same plot reassigned to him, but this is far from the concept of individual ownership which is fixed until title is extinguished by sale or exchange.

Individual property among primitive peoples seems to begin with what the individual gathers or produces. His fundamental right is, therefore, based upon his labor and his good fortune, as when he secures game by reason of a lucky shot or an accidental meeting with the animal killed.

In an earlier section, we stated the gross economic patterns in human living, as hunters, farmers, and herders, etc., so it now remains to review the equipment for living, or what peoples manufacture to serve their needs, physiological as well as emotional. A large part of this equipment falls under the head of arts and crafts, such as work in wood, stone, bone, ceramics, textiles, clothing, metals, chemistry, the use of power, as water, steam, electricity, etc.

CLOTHING

We assume that were the climate mild enough, man could survive without clothing. The approximately nude peoples of the world were the more primitive tribes in tropical areas, such as Central Africa, Australia, New Guinea, various Pacific islands, parts of southeastern Asia and of tropical South America. Fully dressed primitive peoples formerly resided north of 50° latitude, but civilized and barbaric tribes wear a good deal of clothing even in tropical countries, where elaborate clothing takes on the form of luxury rather than necessity. Even a seasonally cold climate does not always force man to adopt adequate clothing. In Tierra del Fuego the local Indians have been seen barefoot in snow and otherwise poorly clad. The Eskimos, Siberians, and Laplanders were forced to wear heavy skin garments or freeze. In fact, tailored garments, cut to completely cover the body seem to have originated with the northern hunters, perhaps they show the way in which cave man finally solved the problem of living in Europe in the ice age.

Skins lend themselves readily to the tailoring process. Cloth, especially primitive cloth, tends to ravel out if



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Fig. 39. Cree Indian Boy in winter costume of loosely woven strips of rabbit fur. Such costumes were widely used among the aborigines of the North American continent

cut, so we find the tendency to drape an uncut fabric around the body as did the Egyptians, Greeks, and Romans. Hence, to weave a shirt, the body of the shirt might be woven as a tube large enough to slip over the body but with holes where the sleeves should be. Next, smaller tubes of cloth will be woven for sleeves, one end of each being sewed to an armhole in the shirt. In this way an entire shirt could be woven in three pieces and the garment assembled without cutting any part of the fabric. Woven shirts of this type may be seen in museum collections from Peru, Mex-

ico, and southwestern United States. Perhaps some of the crudest woven garments are those of certain American Indian tribes, woven of twisted strings of rabbit skins and fur. First the tubular body is woven, then the two sleeves, after which the three parts are joined by a kind of sewing. Pants are made in three parts, and similarly joined. This method of weaving strips of rabbit skins is a simple type of weaving which has spread over the greater part of Canada and found its way down through the Rocky Mountains into the arid plateaus. There is no way by which the age of rabbit-skin weaving can be determined, but we suspect that it was devised by a weaving people.

Even the early students of clothing recognized its two quite different functions, to give protection and to decorate. Nude people resort to decoration by painting, by scarifying the skin, and by the use of garters, girdles, tassels, etc. The values the wearers place upon these objects are aesthetic. It was once assumed that wearing clothes was an expression of modesty, an effort to conceal sex characters, but that can scarcely have been the original motive, since, as Darwin observed, nude-going natives revealed signs of shame when first seen clothed. He believed that shame was a reaction to the unusual in costume and not to its presence or absence. Among a people who regarded



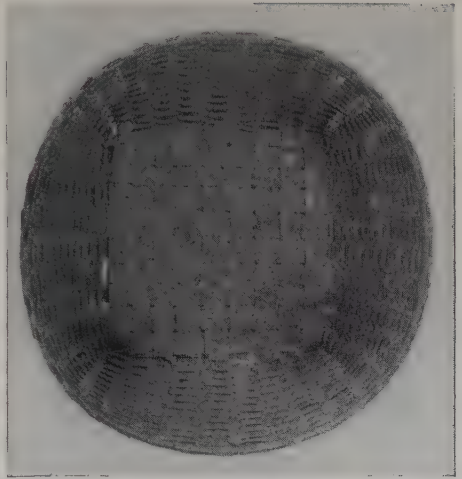
American Museum of Natural History

Fig. 40. Dress shirt for a man, Blackfoot Indians

nudism as the normal procedure, dressing would be condemned as immodest. Apparently the significant factor is that dress and clothing are readily and spontaneously standardized to co-ordinate with sex differences, perhaps even to emphasize sex differences. Further, there seems to be a universal tendency to prohibit the wearing of either the dress or the clothing of the opposite sex.

It is often stated that among primitive peoples the males are more elaborately dressed than the females. Note that the term "dressed" is used instead of clothing, for in cold countries the amount of clothing worn by each sex is approximately the same. This does not necessarily mean that men enjoy beautiful clothes more than women, because in civilized societies the condition seems to be reversed. In primitive society men dress for ceremonial activities, in which case what they wear is symbolic, for it has a meaning; its beauty is secondary.

Many examples of this will be found in the literature of anthropology. The well-known feather headdress of the Plains Indians in North America was originally worn by a man who had killed many enemies, since the custom was to add a single feather to the hair for each enemy killed. When the number became large, it was symbolized by a full headdress. This is the tradition and seems probable. What we do know is that in time such a headdress was the standard dress for a leader or a distinguished man, that it had symbolic value. Women took a less active part in ceremonies, not infrequently being prevented from even seeing them, and so would not wear symbolic dress, or at least not such elaborate dress as that worn by men.



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Fig. 41. Wicker baskets made by the Shinnecock Indians of Long Island. A crude, simple form of weaving which, nevertheless, served their requirements

Finally, dress or clothing, though highly standardized, varies in quality and excellence in fabrication, and so even among primitive peoples, reveals differences in riches. A good hunter with an industrious family will naturally show superiority in dress and clothing; likewise, if weaving cloth is practiced, the family with the most skillful and industrious weavers will make the best showing. The folklore of primitive people reveals incidents based upon the recognition of such differences and the usual social injustices which may accompany them. If one should visit a large museum or look at the picture of different peoples such as may be seen in publications similar to the *National Geographic Magazine*, he will soon come to realize that differences in modes of dress and clothing serve to characterize people more vividly than their facial appearance seems to justify. In short, tribal and national cos-

tume is the obvious easy way to classify them.

WEAVING

We commented briefly upon this subject in Chapter 27, but the textile arts and crafts are so fundamental and so important at all stages in human cultures that some further discussion is necessary.

The principle of weaving is so simple and obvious that no living peoples seem entirely ignorant of the process in its simplest form. Such tricks as twining a twig or stem in and out between stakes, or the poles of a shelter, must have been discovered at a very early period. The beginnings of basketry and matting are also obvious, so that all living peoples know something about them. Yet, real basketry does not appear in the earliest horizons in Kentucky nor have traces of it been found in Stone Age sites. Of course, allowance must be made for its perishable nature. We can, however, be certain that in most places basketry appears before pottery.

The crudest conceivable baskets were those made by the Tasmanian women, when they plaited a few broad, long leaves of grass together to form a carrying basket for shellfish. This basket makeshift was promptly cast aside when they reached home. Crude as this was, it did require an understanding of the principles of weaving. At times the Tasmanians made a more permanent form of basket by a kind of coil, or lace, process. Curiously enough, the natives of southern Patagonia made similar baskets. Baskets are so simple and useful that they have survived since early times, the craft having a place in all civilized culture.

Basketry has two functions, utility and decoration. The making of a fine basket gives joy to the weaver. If the materials are uniform in size and appearance, the weaving presents uniformity and symmetry. In addition to the precision and beauty of stitch, a basket has form or shape by which its beauty may be readily enhanced. Finally, designs may be produced by manipulating the weave as in passing over two, under one, etc. Pleasing and beautiful, though complicated, patterns are produced in this way. Dyes may be employed to vary the colors of the weaving materials, thus producing designs in color.

The most beautiful baskets known were being made by the Indians of California when first discovered, but fine baskets were also made in Africa and South America. The archaeology of Egypt and other semiarid countries reveals examples of good basketry. The best introduction to the subject will come from visits to a large museum where anthropological collections are shown. Note should be taken of the absence and presence of baskets in the collections from different tribes and regions.

Special books have been written about baskets. We can learn that all the known methods of basket weaving can be comprehended as woven and coiled (or sewed). A partial scheme of classification is given here.

First, there are the two main groups, woven and coiled (sewed). Coiled baskets are a class to themselves, since, like coiled pottery, they are begun at the bottom and rise spirally, each round sewed to the preceding. They are subdivided not according to the sewing but according to the material in the coil, or foundation, which may be grass founda-

tion, single rod, two rod, three rod, etc.

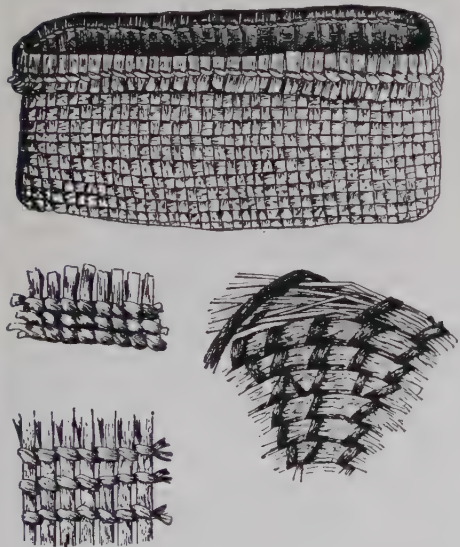
Woven baskets are wicker, splint (straight and twilled), and twined (two-ply or three-ply). There are special tricks for ornamentation and for beginnings, as well as for edges. In North America the great basketry area is the Pacific coast and the adjoining plateaus. Neither the Plains Indians nor those east of the Mississippi made basketry a fine art. There was no part of South America comparable in the production of basketry to that of western United States and Canada.

Basketry designs have been studied in detail. Almost without exception they are geometric. The large stitches in basketry make it difficult to be realistic or to attempt to decorate with pictures, but do lend themselves to the building up of patterns. The bead and porcupine-quill work of the



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Fig. 43. A Pomo Indian woman of California weaving a basket



Wissler

Fig. 42. Basketry weaves. Top, straight weave; left, close and open twine; right, coil

Plains and the eastern Indians are examples. In fact, the designs of the Plains tribes may be considered as basketry designs. Now and then an Indian basketmaker attempts a realistic design, but it is always awkward.

Baskets are generally used as containers for carrying and storing food, as well as other materials. In the main, they are made of stiff materials, as twigs, grass, stems, leaf-ribs, splits of cane and wood, roots, etc. When they are too flexible to stand alone they are classed as pouches and bags. On the Pacific side of North America from southern California to Sitka, Alaska, some baskets were so closely woven that they would hold water and were used frequently to cook in with hot stones. In California the finest baskets made by some tribes were saved to be burned at funerals. To such an extreme did this custom go that a woman spent a great part of

her time making fine baskets, never used, but saved to be sacrificed at her funeral. The more artistic and the more perfect the weave, the more these baskets were valued for such purposes. However, the demand for such baskets by white collectors became so great that the custom of burning baskets at funerals is now nearly extinct.

SPINNING

We are now to consider the fundamentals in the textile arts—cordage and cloth. These subjects hold a large place in our civilization and are a lifetime study in their entirety. They are not a part of anthropology, as such, but the spinning and weaving

of primitive peoples is a part of anthropology. Further, the primitive peoples discovered and used the simple fundamentals of the textile arts. Modern civilizations have done little but find new ways of increasing the materials necessary to the production of textiles on a large scale and the application of power to automatic machinery. This is the contribution of modern man to the textile arts, but everything now done by spinning and weaving machinery was discovered and well executed by hand work under primitive conditions. As evidence of this, we note that every main type of weave is found in hand work.

However, the making of thread and cordage underlies cloth production,



Sante Fe Railway Co.

Fig. 44. Navaho women carding, spinning, and weaving wool



Wissler

Fig. 45. Mexican textile designs. The figure is from a prehistoric Maya drawing, but the other designs are modern

lace making, netting, and sewing. Even skin garments are sewed up with sinew thread. Cordage is the universal method of binding and joining in primitive woodwork and still plays a large role in our culture. The metal substitute for cordage is wire. The original materials for spinning were vegetable fibers, and vegetable and animal wools and silks. Most vegetable fibers are long, strong filaments, found in the barks and leaf stalks of many plants. The chief sources in the New World in aboriginal times were the inner barks of a few species of trees, and the stalks of the milkweed, nettle, and wild hemp, while in the

Old World flax and hemp dominated. These fibers still prevail in civilized cultures, especially flax and hemp. Among vegetable wools, cottons lead. Sheep wools have displaced most of the other animal wools used in spinning. For a long time silk had no competition, but now the chemical production of silk is supplanting true silk and threatens to displace cotton and wool.

The mechanics of spinning are well understood. Any fibers long enough to twist upon each other, and rough enough to resist pulling out after such twisting, will make good cordage. Such fibers must be relatively long

and strong. Once twisted tightly they tend to remain twisted, and are thus able to support heavy weights or to offer strong resistance to pulls. The best fiber for cordage is one with a high level of resistance to water. The first spinning was obviously twisting by hand. Exceedingly fine threads can be twisted in this way, even finer than can be spun with machines, because the finest threads are too weak to stand the necessary pulls in machine spinning. For example, ancient cloths woven of hand-spun cottons from Peru have shown threads of 300 to the inch, whereas modern machine cottons rarely exceed 60 to the inch, because finer threads are impracticable. In this instance, skilled fingers can do what machines do not do well. The fundamental principle in labor-saving machinery is that it does quickly and cheaply what was originally done by hand.

The most primitive method of spinning is to twist the fibers between the ends of the fingers and thumbs, or to roll this thread under the palm of the hand upon a firm surface, usually the skin of the thigh or of the lower leg. The beginning of mechanization was the invention of the distaff and the spindle. Most thread and cordage is either of one, two, or three plies; that is, a single strand may be twisted and used in that form, but the usual procedure is to combine one or more single, twisted threads into one. This will be revealed if you untwist the end of a thread, cord, or rope. The invention of the spinning wheel was a big step toward the machine spinning and the complete elimination of hand work.

The making of good thread or cord was the essential step to the weaving of cloth. In the case of basketry the

materials for weaving were furnished by nature but lacked the flexibility and softness needed in cloth. Cloth presented other new problems. For example, when weaving a basket the stiffness of the warp strands held them in position for the weaver, whereas the extreme limberness of cord made it necessary to suspend the strands. One idea of a loom is a frame on which the warp threads can be stretched to hold them in position for weaving, yet there still survive in the world primitive forms of weaving in which the warp threads hang loosely from a bar of wood. In such cases the weaver begins at the top and weaves downward, whereas in a loom frame the weaver begins at the bottom and so weaves upward. The Greeks at one time used the suspended warp type of loom, so did the Egyptians, the Lake Dwellers, the Scandinavians, and in North America the Chilkat and the Central Algonquin Indians. The rectangular frame, or the two-bar loom, came later, probably first used in the ancient civilizations of western Asia and independently invented in pre-Columbian America. Later important inventions were shedding devices for parting the warp strands to enable the weaver to pass the wool threads quickly from one side to the other by means of a shuttle. These inventions made the power loom possible, leading eventually to the Jacquard looms of modern industry, by which elaborately patterned cloths, carpets, etc., may be produced mechanically.

Dyeing and printing are an important part of textile production. These procedures were invented so long ago that their origins are unknown. Probably hand printing preceded block and roller printing, but both were

practiced in the ancient Old and New Worlds, probably independently invented in the two areas. We stated before that the weaving of cloth was invented in the Age of the Farmers and Herders, but that the weaving of baskets seems to have begun in the Age of Hunters. Since needles are found in the Solutrean period of the Old Stone Age, we assume that the invention of twisting thread is still older.

CERAMICS

The ceramic craft is comparable to textiles in that its importance and magnitude does not diminish with time. Once the principle was discovered, the various uses of ceramics continued to multiply and to diffuse

over the world. We suppose that sun-dried bricks and clay basket linings were used before the making of pottery, but the use of clay in and around fireplaces would offer opportunities to discover that firing clay would produce a chemical change, making the substance insoluble in water and indestructible in the fire. The Zuñi Indians have a tradition that they first lined shallow basket trays with clay to protect the basket work from coals of fire put into it to parch seeds and grains of corn. The corn could be kept from burning by shaking the tray to keep the grains in motion. Incidentally, archaeologists have found in sites occupied by some basket-making peoples, such baskets lined with clay. In other neighboring sites are



Museum of the American Indian

Fig. 46. Pottery making as it is practiced by the Zuni Indians of New Mexico. Note that a potter's wheel is not used. To the right, the design is painted on the surface of the shaped pot

heavy, crude clay vessels which show traces of attempted firing. This has been taken as a suggestion that pottery vessels were developed from the use of clay-lined baskets. But since similar examples of clay-lined baskets have not been found elsewhere, the tendency is to reject this as evidence that pottery did originally evolve in this or any similar manner.



Museum of the American Indian

Fig. 47. The final stage in making the Zuni pottery is firing the vessels

Some form of clay is always used for pottery, but is mixed with other materials, or "tempered" as potters say. Various substances are used for tempering—the Indians in North America mixed clean sand, pulverized potsherds, shells, granite, etc., with the clay before shaping the pots. Some of the village Indians of New Mexico use equal parts of sand and clay. Tempering seems to prevent cracking as the freshly modeled vessel dries and again as it is fired.

Water is mixed with the clay before shaping the vessel. Shaping may be freehand or upon a wheel. Oddly enough, while a wheel has been used

for ages in parts of the Old World, the earlier pottery of that part of the world was not made upon a wheel, nor was a wheel used anywhere in the New World before 1492. The aboriginal potters followed two methods, coiling and paddling. In the first method the potter began by beating a mass of clay into the shape of a shallow dish, which he then placed into a shallow pottery dish, or a basket. Next, long, thick rolls of clay are shaped between the hands and coiled around upon the edges of the shaped clay base. This proceeds until the rim of the pot is reached. The walls of the pot are now clumsy and thick, but after the vessel is pressed into the right shape, the marks of the coils are scraped away with a piece of gourd or a potsherd until they are the desired thickness. Then the pot is set in a safe place to dry.

Most primitive pottery is unglazed but decorated by painting with a slip of earth chosen according to the color desired. The potter knows that certain kinds of earths will burn red, others cream-colored, others yellow, etc. A thin solution is made with water and the variety of earth chosen. This slip is rubbed or painted over the surface of the pot and polished or smoothed by rubbing. If additional decoration is desired, designs may be painted upon the polished surface according to the color desired, using vegetable or mineral paints as the case may be. When thoroughly dry, these vessels are fired, usually in the open, by piling fuel around—but not touching—the vessels.

The glazing of pottery is an advanced technique produced by a coating of certain earths which, when heated to the right temperatures, will glaze or run like glass. When the ves-



American Museum of Natural History

Fig. 48. Prehistoric gold ornaments from Panama. The age of the City States in the New World developed skill in the working of gold and copper

sel cools it will have a smooth, shiny surface. If both the inside and outside of the vessel are glazed it will not absorb liquids. Most of the pottery we use and the dishes upon our tables are glazed in this way. Primitive and early potters did not understand glazing. It was not practiced in the pre-Columbian New World.

Early pottery is rarely painted, so it is uniformly black or red, the natural colors of the fired clay. Such pottery is often plain but may be decorated by incising or stamping. Decorated pottery of this sort is found both in the Old and in the New World. It appears early in the Age of the Farmers and Herders, and traces of it have been observed in the closing years of the Stone Age hunters. At first pottery seems to have been used for boiling food and occa-

sionally for storage. Later, in dry, hot countries it was used for cooling water also, for if a vessel is not glazed, water will slowly soak through the clay walls and evaporate from the outside, thus cooling the water within. As the culture of the pottery maker advanced, some of it was made beautiful and so valued as art. Figures of men and animals were modeled and among peoples cremating their dead, large vessels were made in which to deposit the ashes.

In dry countries bricks were usually sun-dried, but when the climate was moist they could be made durable by firing. We are all familiar with the use of fired bricks and tiles.

METALS

The transition from stone to metals could have been made gradually.

Gold, for instance, is often found in nuggets, reasonably pure, and can be worked into any desired shape by hammering. In a few places in the world, pure copper is found, so pure that it can be shaped by the hammer. The unique quality and fineness of

the Farmers and Herders but was intensified in the Age of Cities. The traditional way of outlining the sequence of technological history is by ages as Stone, Bronze, Iron, and Steel, the assumption being that the use of these metals was decisive in rating the



Black Star from the Bettmann Archive

Fig. 49. Use of bellows for smelting metal. The pressure upon the bellows is applied by the feet and the air valve is controlled by the hands

these metals would attract the attention of primitive man and suggest a mode of utilizing them. Gold was too soft and scarce to suggest that it be used as a substitute for stone in the manufacture of stone tools, but in a few places in the world, relatively pure copper was found in bulk sufficient in quantity to supply tribes. Logically there should first of all be a copper age, a period in which tools of copper displaced tools of stone, but the use of copper soon ushered in the use of bronze, an alloy of copper and tin or zinc, so it is customary to speak of a bronze age as including the age of copper.

In the brief outline of the world's history given on page 715, the use of metals seems to begin in the Age of

values of cultures and civilizations. The outline we have proposed regards the use of metals as but a part of the cultures concerned, their power and values depending upon the whole round of cultures rather than upon any one part of it.

In the Old World the use of copper is provisionally dated as earlier than 4000 B.C. The earliest extensive working of copper was in the peninsula of Sinai, in Egypt, where there were extensive deposits of copper, now practically exhausted. Cyprus was another locality where this metal was once abundant. Where and how the invention of smelting copper ore occurred we do not know, though it was probably somewhere in Asia Minor. Copper tools were soft, but

their cutting edges could be hardened by pounding. However, copper was first used for ornaments rather than for cutting tools. Armlets, finger and nose rings, beads, anklets, jinglers, bodkins, needles, and arrow points of copper are common in early archaeological collections; later celts, knives, and axes appear.

No one seems certain as to when bronze was discovered, but probably it came naturally with the casting of copper objects. Sooner or later some primitive metal workers noted that if tin or zinc were mixed with copper, casting was not only easier but the resulting alloy was harder, so better for swords, axes, and knives. When the Romans landed in England they found the natives using swords of tin which were so soft that the bronze and iron shields of the Roman soldiers bent their edges, rendering them worthless. The use of bronze spread rapidly in the Old World and wherever it went it stimulated art work in metal and ingenious methods of casting thin-walled vessels. In China zinc was used to form bronze, in western Asia and Europe tin was used. A method of casting called the "lost wax" process was devised and is still used in the casting of fine art objects. If the object is to be cast solid, it is first modeled in wax, then coated with clay. Enough bronze is placed in a part of the clay mold connected with the wax figure, and the entire clay mold is placed in the furnace, the wax below and the bronze above. When the bronze melts, it displaces the now liquid wax and when removed from the furnace, the clay mold is broken open releasing the bronze casting. This method of casting bronze was known in pre-Columbian Peru, as well as in the

Old World. Since in no other part of the New World was the method practiced, it is assumed that it was independently invented in the two places. It is true that bronze was made and cast in West Africa, but since this is in the Old World where land connections are direct, it is less likely to have been an independent invention.

IRON AND STEEL

Iron ore is abundant, at least there are here and there large deposits of it, though it is found only rarely in a moderately pure state. In Africa, however, some iron ores are so rich that they can be heated in an open fire and purified by beating, or forging. The pre-Columbian metal workers of Peru and Central America did not discover iron or develop an iron industry. The only iron that archaeologists have found in the New World are a few rare scraps of meteoric iron used for ornament or for the practice of magic. The Eskimo of Greenland did use iron flakes beaten off the surface of a large meteorite discovered in that country and brought to New York by Peary. These flakes were set in a row, in a groove in a piece of bone to form a kind of knife. Similar knives formed by a row of small stone flakes were used in ancient Europe and Asia, and also by some of the Eskimos. Hence, the use of meteoric iron followed the old stone-tool pattern. Some meteoric iron beads have been reported from Egypt, dated long before true iron makes its appearance.

Where and when iron was first reduced from ore and put to use is still uncertain, but it seems to have been widely used in Asia Minor because the Assyrians are the first to use it

extensively in war. The metal seems to have reached Egypt about 1200 B.C., Greece sometime before 1000 B.C.; China began to use iron around 600 B.C., and its appearance in western Europe was much later.

Museum collections from Africa, Madagascar, East India, and China often contain sample outfits for the forging of iron, and sample objects like tools and weapons produced in each case. Students of culture diffusion often point to the absence of the familiar bellows in Peru and other New World areas. In South America the furnace for melting bronze, copper, gold, and silver was operated by blowpipes. To increase the blast the number of persons who blew through tubes was increased. There is some evidence, however, that they understood how to utilize the draft created by individual minor fires in side openings to the furnace. The bellows, on the other hand, was widely diffused in the Old World. In southeastern Asia and Madagascar the bellows reminds one of a double-barreled compressor. Each barrel is a wooden cylinder with a valve so arranged that as the plunger descends, the enclosed air is forced through a clay tube under the fire on the forge. When the two cylinders are worked alternately a fairly steady series of air puffs are delivered into the fire. The African types are a pair of skin bags in which the valves are operated by hand, the air being forced out of one while the other is filling, and a pair of wooden conductors, or horns, with loose skin heads in which valves operate automatically, similar to those in pumps. The population of Madagascar represents an ancient settlement of people from the East Indies, and it was for this reason that the bellows used in

the East Indies found its way into Madagascar but did not penetrate the negro cultures of Africa.

The use of a true blast furnace for smelting iron ore did not arise until about 1400 A.D., after which improvements in the fabrication of steel and alloys were first slow, then rapid. It is now the fashion to distinguish between the ages of iron and steel.

In conclusion, it is obvious that metals, especially iron and steel, have come to hold a prominent place in the culture of man. Taken with the use of water, steam, or electric power, they largely explain the industrial age in which the peoples of the world now live. Alone they do not explain culture and history but without an understanding of them, the phenomena of the age cannot be understood.

TRANSPORTATION

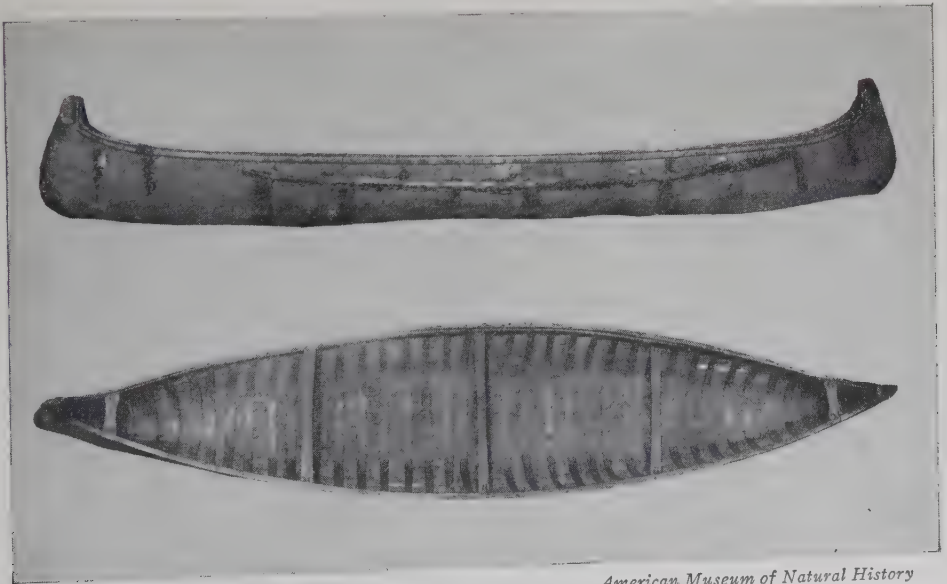
To carry goods from one place to another is fundamentally important in all cultures. Man seems to be the only mammal that carries baggage with him wherever he goes. He has baggage because he has a culture requiring more or less equipment. As his culture intensifies, he requires more baggage and so must either stay at home or devise ways of transporting it and himself. Originally he went afoot and carried what he could upon his own back or upon his head. Ancient Mexico is an outstanding example of an advanced people without domesticated pack animals. Even within recent times men and women could have been seen carrying large heavy packs along the highways, and when Cortez invaded Mexico, the roads between villages were filled with carriers of goods. Relay runners carried messages from one town to

another. It is said that fresh sea fish were delivered in Cuzco, the ancient Inca capital nearly 300 miles from the coast, by swift relay runners.

The invention of boats came early in the history of man, probably in the late Stone Age. From that time on every people seem to have made some use of them. The first boats, of course, were paddled; sails came into use later. From ancient times sea-going boats were rowed, usually by convicts, but used sails also. Even in Egyptian days sea-going boats were equipped for war.

Many people are interested in the first steps in the invention of boats. This question may never be satisfactorily answered, but the most probable suggestion came from experiences with floating trees and logs. The making of a crude raft and sliding it across or down a stream naturally suggests itself. Once a people became accustomed to the use of such

devices, boats would follow as a matter of course. All the world over the most primitive peoples use the hollowed-out tree trunk, or the "dugout." Even civilized peoples occasionally resort to this simple device. The size limitations in the dugout are the diameters of the trees used. The New Zealand natives made long canoes but rarely did they find trees large enough to provide for two paddlers side by side, hence, to provide more man power the length of the canoe had to be increased, but a limit to this was soon reached, because the straight, free trunks of trees are seldom of great length. The largest dugouts known were used by the Indian tribes between Puget Sound and the Aleutian Peninsula off the Northwest Pacific coast of North America. Some of the dugouts preserved in museums reach a length of 65 feet with a maximum width of eight feet, truly a remarkable piece of work.



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Fig. 50. Birchbark canoes of the Woodland Indians of North America



American Museum of Natural History

Fig. 51. Model of a balsa or reed raft used by the Miwok Indians of California

A dugout can be made with simple, primitive tools. The interior is usually burned out, the canoe builder watching the fire to see that only the part of the canoe to be removed burns away. The final finishing of the canoe could be easily accomplished with a stone adz. It is in the final shaping of the canoe that the genius of the primitive canoe builder is demonstrated. After the canoe is completely hollowed out, the edges of a gunwale follow the original lines of the log, whereas the widest part of the true canoe is amidship. So to shape the dugout the primitive canoe builder fills the hollow with water which is then made to boil by dropping in hot stones. After a time the heat and water softens the wood so that the sides of the canoe can be spread; when dry they will retain this new position.

When and by what steps the canoe builder arrived at the idea of building up the sides of a boat with planks is not known. Occasionally primitive peoples increase the depth of a dugout by setting up planks around the edge. On the other hand, specimens of primitive canoes have been seen which consisted of a kind of dugout keel, up from the sides of which rose a few overlapping planks. Yet the true plank canoe demands a framework to which planks can be fastened as in the case of a wooden ship. Such frames are seen at their best among primitive bark- and skin-covered canoes. The birch-bark canoe of the American Indian is a well-known example; a light, delicate framework of wood is first constructed, over which is fitted a cover of birch bark. Such a canoe is at least 12 feet long and

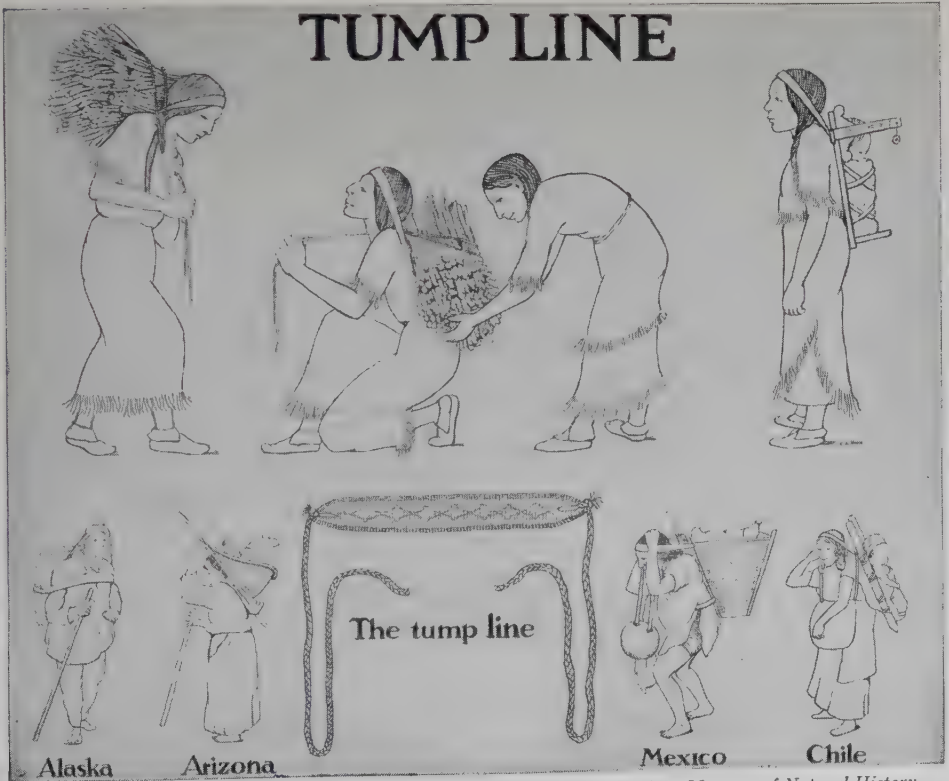
capable of carrying two persons; longer canoes will carry more passengers and goods.

Good skin-covered boats are made by the Eskimo, as the kayak and the woman's boat. Most primitive canoes are handled with paddles, in which case the paddlers sit or kneel, facing forward; in larger boats rowlocks are used, the rowers facing the rear. Practically all primitive tribes use paddles, as throughout Africa, the islands of the Pacific Ocean, and the entire New World. About the only exception is the Eskimo, who handles the kayak with a double paddle but rows the skin-covered boat, often using sails also. The chances are that

the Eskimo derived oars and rowlocks from the Europeans, perhaps from the Scandinavians when they settled in Greenland.

It remains to mention another type of boat, the balsa. In Peru, Tasmania, and in California, reeds are tied into cigar-shaped bundles and, when very large are fitted with sails. In reality, the balsa is a kind of raft large enough to float and support the load to be carried. It is suitable for short journeys but eventually becomes waterlogged and useless. Where suitable reeds are abundant, such boats are easily made but are slow and require a great deal of hand power in paddling or rowing.

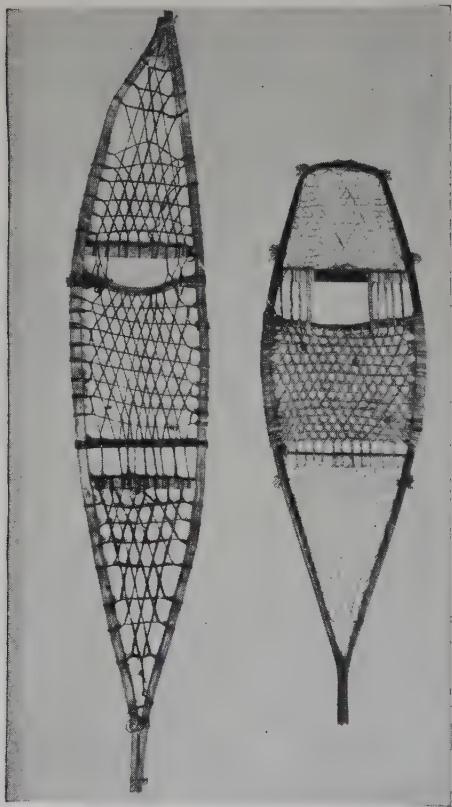
TUMP LINE



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Fig. 52. A prevailing New World method of carrying burdens is the tump line

The canoe lacks stability and is unsuitable for rough water, but in the Pacific islands two long dugouts may be joined by crossbars and floored over, thus forming a kind of raft. When sails are added, such a cata-



American Museum of Natural History

Fig. 53. Snowshoes of the Cree and Ojibway Indians

maran is a seaworthy boat which is difficult to sink or to capsize. In Malay countries and many parts of the Pacific, a dugout may be made stable by oars, or two outlying floats joined to the sides of the canoe by poles. These are called outriggers and by greatly broadening the base of the canoe make capsizing almost impos-

sible. Even large frame and plank boats are stabilized in this way. Such seagoing boats enabled the island inhabitants of the Pacific to reach the distant groups of islands such as New Zealand or Hawaii. Knowing nothing of the compass, they constructed a kind of lattice frame of bamboo strips with which they took observations by noting the positions of certain fixed stars, and steered accordingly. When Europeans came upon the scene they found the natives able to find their way from one of their island groups to the other. The Scandinavians, or Norsemen, found their way to Iceland and Greenland without the aid of a compass, but in the days of Columbus all European navigators used the compass. One need not be told that the beginnings of modern civilization lie in the circumnavigation of the world, or the ability to guide ocean-going ships to all parts of the world.

Returning to land transportation, we observe many primitive devices for fixing loads of baggage to the human head and back. Travel over snow and ice was facilitated by the invention of suitable footwear, skis, and snowshoes. The dragging of the load upon the snow or ice probably led to the invention of the toboggan in America and the sled in Europe and Asia. The toboggan is usually drawn by a man or woman walking on snow shoes, whereas, the sled of the Eskimo is hauled by both men and dogs. Neither the sled nor the toboggan is of much use in summer, at which season the Eskimos and the northern Indians use boats and canoes wherever possible. In the packing of baggage, domestic animals have for long played a major role. The dog we have mentioned, but he also was made



University Museum, Philadelphia

Fig. 54. A Cheyenne Indian family with their travois, a primitive cart

to carry packs tied upon his back, as did the ass, the camel, the ox, the horse, and the mule.

The Plains Indians invented a device for hauling baggage without wheels, known as a travois, but the cart and the wagon of the ancient Old World was the outstanding epoch-making invention. No wheel having been devised in the New World, and few good draft animals being available, all the poor Indian could do was put the load upon his own back or have dogs drag it over the surface of the earth on sleds or travois. All this changed quickly when the Plains Indians acquired horses. Simple water transportation they were familiar with, and they used it when and where climate permitted. When rivers were too deep for wading, the horses were forced to swim to the other side, but before

the horse was available, the Plains Indians had devised a ferryboat, circular and tub-shaped, made by stretching a buffalo skin over a framework of poles. Baggage, old people, and young children were ferried across streams in such boats, adults and youths swimming. After horses were in use, a swimming horse often towed such a boat.

SUMMARY

We have reviewed briefly most of the topics which make up anthropology as the term is used in the United States. The field of study is so vast and complicated that the reader wishing to go further with it should consult such special books as fall under the headings of primitive languages, race anatomy, ethnology and culture, primitive society, and finally, archaeology.

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